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(54) **IRON-BASE SOFT MAGNETIC ALLOY.**

(57) A novel iron-base soft magnetic alloy having excellent soft magnetism, particularly a low coercive force and a high permeability in a high-frequence range, and low iron loss. This alloy is produced by adding a given amount of aluminum and preferably further given amounts of elements such as niobium to an Fe-Si-B alloy to give an amorphous alloy, forming the alloy into thin belt, powder, thin film, etc., and heat treating the resulting alloy, thus giving an alloy composed of at least 30% of a crystalline portion and the balance of an amorphous portion.

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Technical Field

The present invention relates to an Fe-base soft magnetic alloy and, in particular, to an alloy having excellent soft magnetic properties.

Background of the Invention

Fe-base amorphous magnetic alloys having a high saturation magnetic flux density are known to be used as magnetic core materials for high frequency transformers, saturable reactors, choke coils, etc. However, though Fe-base amorphous magnetic alloys are lower priced than Co-base ones, the former have the drawbacks of high saturation magnetostriction and core loss and a low permeability.

A method of producing an Fe-base amorphous alloy has been reported recently in which a thin Fe-base amorphous ribbonformed by rapidly quenching an alloy composition melt is heat-treated to generate fine crystalline particles having a particle size of about 100 Å or so. The Fe-base amorphous alloy thus produced exhibits better soft magnetic properties than any other conventional Fe-base amorphous alloys (Japanese Patent Application Laid-Open No. 64-79342, Japanese Patent Application Laid-Open No. Hei1-156452, U.S.P. 4,881,989). The reported Fe-base amorphous alloy has a basic composition of FeSiB and additionally contains high melting point metals such as Cu, Nb, etc., in which the alloy structure has been finely crystallized to obtain fine crystalline particles having a particle size of about 100 Å or so. Accordingly, the Fe-base amorphous alloy has become possible to have a lowered saturation magnetostriction, though conventional Fe-base amorphous alloys were difficult to have it. As a result, the reported Fe-base amorphous alloy is said to have improved soft magnetic properties, especially improved frequency characteristics of magnetic permeability.

However, when Cu is added to the alloy, Cu tends to gather by itself to cause heterogeneity of the alloy. Thereby, there can be such drawback as difficulty of forming a thin film by a single roll method or sticking of Cu to the nozzle which brings on a change in the composition of the alloy.

On the other hand, regarding Cu-free fine crystalline soft magnetic alloys, Fe-Ta-C alloys have been reported (Hasegawa, et al., Journal of Applied Magnetics Society of Japan, 14, 313, 1990). However, these alloys could not be said sufficient in view of the practicability (economical efficiency) thereof.

One object of the present invention is to provide a novel Fe-base soft magnetic alloy, which is a soft magnetic material substitutable for the above-mentioned conventional soft magnetic materials and which has an extremely low saturation magnetostriction with having excellent high frequency magnetic properties, in particular, having a high permeability and a low iron loss in a high frequency region.

Another object of the present invention is to provide a Fe-base soft magnetic alloy which is a metal-metalloid alloy having a relatively low melting point and which can be produced by the use of any conventional device for producing ordinary magnetic materials.

Disclosure of the Invention

Intense reserches and studies of various Fe-base soft magnetic alloys in view of the above objects have revealed that addition of Al to an Fe-base Fe-Si-B soft magnetic alloy can provide an improved Fe-base Fe-Si-B-Al soft magnetic alloy having excellent soft magnetic characteristics, for example, having an extremely low saturation magnetostriction, and that addition of other particular metal(s), especially Nb, to such an Fe-base Fe-Si-B-Al soft magnetic alloy is effective for obtaining excellent soft magnetic properties of the resulting alloy. The present invention is based on these findings.

Specifically, there is provided in accordance with the present invention an Fe-base soft magnetic alloy which has a composition represented by the formula:

$$(Fe_{1-x}M_x)_{100-a-b-c-d}Si_aAl_bB_cM'_d$$

where M is Co and/or Ni;

M' is at least one element selected from the group consisting of Nb, Mo, Zr, W, Ta, Hf, Ti, V, Cr, Mn, Y, Pd, Ru, Ga, Ge, C and P;

x is an atomic ratio;

a, b, c and d each are an atomic %; and

x, a, b, c and d each satisfy $0 \leqq x \leqq 0.15$, $0 \leqq a \leqq 24$, $2 < b \leqq 15$, $4 \leqq c \leqq 20$, and $0 \leqq d \leqq 10$. In particular, at least 30 % of the alloy structure is desired to be occupied by a crystalline phase (fine crystalline particles), and the crystalline phase is desired to be composed of an iron solid solution having a bcc

structure. M' is preferably Nb.

The Fe-base soft magnetic alloys of the present invetnion contain less than 0.5, preferably less than 0.1 atomic % copper (Cu) and more preferably entirely free of copper in view of magnetic properties.

In the Fe-base soft magnetic alloy of the present invention, Fe may be substituted by Co and/or Ni in the range of from 0 to 0.15 for the value x. Since Co and Ni have a negative interaction parameter relative to Fe, it is believed that they are substituted for Fe in the bcc structure latice by dissolving in the Fe-major bcc solid solution formed during the heat treatment of the alloy of the present invention. Accordingly, it is believed that a magnetostriction constant and a magnetocrystalline anisotropy constant of the bcc solid solution would be reduced. Since the alloy of the present invention where the Ni (and/or Co) content (x) is $0 \leq x \leq 0.02$, particulary $x = 0$, i.e. including no Ni nor Co, has a high permeability, it is preferably applied to such a use that requires a high permeability, as (material for magnetic core of) a common mode choke coil, an inductor for filters, transformers for signals and so on.

On the other hand, in case that the Ni (and/or Co) content (x) is $0.02 \leq x \leq 0.15$, such effect is obtained that the magnetostriction constant and a magnetocrystalline anisotropy constant of the alloy are reduced as noted previously, accompanied with the effect that the alloy has a high permeability. Further, a magnetocrystalline anisotropy is sufficiently induced in the alloy by heat treatment in a magnetic field. Accordingly, the alloy is preferably applied to such a use as (material for magnetic core of) common-mode choke coil, an inductance coil for filters, transformers for signals, a high frequency transformer, a magnetic amplifier and so on. In this case, the Ni (and/or Co) content (x) is preferably $0.02 \leq x \leq 0.15$, and more preferably $0.03 \leq x \leq 0.1$.

Al is an essential element of constituting the alloy of the present invention, and addition of a determined amount (more than 2 and not more than 15 atomic %) of Al to the alloy causes enlargement of the temperature difference (ΔT) between the crystallization temperature (TX_1) of the soft magnetic crystals having a small magnetocrystalline anisotropy (Fe-base bcc solid solution) and the crystallization temperature (TX_2) of the crystals of interfering with the soft magnetic property (for example, Fe-B crystals) to thereby inhibit formation of Fe-B crystals in heat-treatment of the alloy composition and lead the resulting alloy to having sufficient soft magnetic properties by heat-treatment at a relatively low temperature. Fig. 1 shows the relationship between the crystallization temperature of an Fe-base soft magnetic alloy to which Al is added and the Al content atomic % in the alloy. From Fig. 1, it is noted that increase of the Al content in the alloy causes simple decrease of TX1 while TX_2 is relatively unchanged irrespective of the variation of the Al content, so that the increase of the Al content in the alloy thereby causes increase of the temperature difference (ΔT) between TX_1 and TX_2.

In the present invention, the Al content (b) in the alloy is more than 2 atomic % and not more than 15 atomic %, preferably from 2.5 atomic % to 15 atomic % and more preferably from 3 to 12 atomic %. Determination of the Al content in the range 3 to 12 atomic % causes a high permeability and a low core loss. In case that the Ni/Co content (x) is $0 \leq x < 0.02$, especially $x = 0$, the Al content (b) is preferably from 6 to 12 atomic %, more preferably from 6 to 10 atomic %, and most preferbly from 7 to 10 atomic %.

Since Al, similar to Ni (Co), has a negative interaction parameter relative to Fe, it is believed that addition of Al results in it's dissolution in the Fe-major solid solution, that is, dissolution in the way to be substituted for the Fe atom in the α-Fe crystal structure and stabilization of the bcc crystal. Thereby an environment of easy self-crystallization in the alloy during heat-treatment yields. Accordingly, since crystal grains having a small magnetocrystalline anisotropy are selectively formed in the alloy by addition of Al thereto, as mentioned above, it is believed that the alloy would have an excellent soft magnetic properties because of such morphology.

Si and B are elements which make the Fe-base soft magnetic alloy of the present invention amorphous in the initial stage (before heat-treatment). The Si content in the alloy of the present invention is from 0 to 24 atomic %, preferably from 6 to 18 atomic %, and more preferably from 10 to 16 atomic %. Determination of the Si content in the said range preferably causes improvement of the ability of formation of amorphous in the initial stage (before the heat-treatment).

The B content (c) in the alloy of the present invention is from 4 to 20 atomic %, preferably from 6 to 15 atomic %, and more preferably from 10 to 14 atomic %. Within the determined range of B, a sufficient temperature difference between the crystallization temperatures (TX_1 and TX_2) can be obtained and the alloy may be made amorphous with ease. The ability of formation of amorphous changes acccording to whether the content of B is more or less than 9 atomic %. In the range of the content of B being 9.5-15 atomic %, particularly 10-14 atomic %, the amorphous alloy including Al is provided an excellent ability of amorphous formation and uniformalized crystal grains are obtained after heat treatment.

The basic composition of the Fe-base soft magnetic alloy of the present invention is composed of the above-mentioned Fe (M), B, Si and Al. In order to improve the corrosion-resistance and the magnetic

properties of the alloy of the present invention, other element(s) M' may be added to the alloy. As M' is mentioned at least one, i.e. one or more of the elements selected from the group consisting of Nb, Mo, Zr, W, Ta, Hf, Ti, V, Cr, Mn, Y, Pd, Ru, Ga, Ge, C and P. Addition of the M' elements is effective for improving the ability of the base composition of Fe-Si-Al-B alloy of forming the amorphous phase of the alloy.

The Nb, W, Ta, Zr, Hf, Ti and Mo elements are particularly effective to prevent crystallization of the Fe-B crystalline which hampers the soft magnetic properties of the alloy or to elevate it's crystallization temperature, whereby it improves the soft magnetic properties of the alloy. Further, addition of these elements to the alloy makes the crystal grain fine. The V, Cr, Mn, Y and Ru elements are particularly effective in improving the anti-corrosion properties of the alloy. The C, Ge, P and Ga elements are particularly effective in the process of forming the amorphous alloy. One more of the foregoing elements can be added. As these elements M', preferred are Nb, Ta, W, Mn, Mo and V. Above all, Nb is most preferred. Addition of Nb results in an extreme improvement of the soft magnetic properties, especially the coercive force, permeability and core loss of the alloy. The content of the M' element(s) is from 1 to 10 atomic %, preferably from 1 to 8 atomic %, more preferably from 1 to 6 atomic %. Addition of the M' element(s) to the alloy of the present invention in such an amount as falling within the determined range forms in the alloy compound(s) of the added element(s) which may retard deterioration of the amorphous phase-forming ability and the magnetic properties of the alloy.

Incidentally, alloy further containing inevitable impurities such as N, S, O etc., is also comprised in the alloy composition of the presnet invention.

The Fe-base soft magnetic alloy according to the present invention has an alloy structure, at least 30 % of which consists of crystal (fine crystalline particles), with the balance of the structure being an amorphous phase. The range of the ratio of the fine crystalline particles in the structure provides the alloy excellent (soft) magnetic properties. In the present invention, even if the crystalline particles occupy substantially 100 % of the structure, the alloy has yet sufficiently good magnetic properties. Preferably at least 60 %, more preferably 80 % or more of the alloy structure consists of the fine crystalline particles in view of magnetic properties.

The crystalline particles of the alloy of the present invention has a bcc structure, where Fe as a main component and Si, B, Al (occasionally Ni and/or Co) are dissolved in.

It is preferred that the crystalline particles to be formed in the alloy of the present invention have a particle size of 1000 Å or less, preferably 500 Å or less, more preferably 50 to 300 Å. The particle size being 1000 Å or less, provides the alloy of the present invention excellent magnetic properties.

The proportion of the crystalline grains to the total alloy structure in the alloy of the present invention may be determined experimentally by an X-ray diffraction method of the like. Briefly, on the basis of the standard value of the X-ray diffraction intensity of the completely crystallized condition (saturated X-ray diffraction intensity condition), the proportion of the X-ray diffraction intensity of the magnetic alloy material sample to be examined to the standard value may be obtained experimentally. Apart from this, it may also be determined from the ratio of the X-ray diffraction intensity of the diffracted X-rays to be proportional to crystallization of the alloy to the X-ray diffraction intensity by the halo effect which is specific to the amorphous phase to be decreased with progress of crystallization of the alloy.

The average size of the crystalline particles is determined from Scheller's equation ($t = 0.9\lambda/\beta \cdot \cos\theta$) by using bcc peak reflection of the X-ray diffraction pattern (Element of X-ray Diffraction (Second Edition), pages 91-94, B.D. Cullity).

In general, the Fe-base soft magnetic alloy of the present invention may be produced by a rapid melt-quenching method of forming an amorphous metal from a melt of the above-mentioned composition. For instance, an amorphous alloy is first formed in the form of a ribbon, powder or thin film by a single roll method, cavitation method, sputtering method or vapor deposition method, the resulting amorphous alloy is optionally shaped and worked into a desired shape, then it is heat-treated so that at least a part, preferably 30 % or more of the whole, of the sample is crystallized to obtain the alloy of the present invention.

Generally, a rapid-quenched alloy ribbon is formed by a single roll method, and this is shaped into a determined shape such as a coiled magnetic core and then heat-treated. The heat-treatment is effected in vacuum, in an inert gas atmosphere, such as an argon gas or nitrogen gas atmosphere, in reducing gas atmosphere such as H_2 or in oxidizing gas atmosphere such as air, after fully de-aired into vacuum. Preferably, it is carried out in vacuum or in an inert gas atmosphere. The heat-treatment temperature is approximately from 200 to 800 °C, preferably approximately from 400 to 700 °C, and more preferably from 520 to 680 °C. The heat-treatment time is desired to be from 0.1 to 10 hours, preferably from 1 to 5 hours. The heat-treatment may be effected either in the absence or presence of a magnetic field.

By the heat treatment of the amorphous alloy being carried out in the aforementioned range of temperature and within the aforementioned time range, the soft magnetic alloy having excellent propertiers

is obtained.

Brief Description of the Drawings

Fig. 1 is a graph showing a relationship between the crystallization temperature of an Fe-base soft magnetic alloy and the Al content therein.

Fig. 2 is a graph showing a relationship between the coercive force (Hc) of an Fe-base soft magnetic alloy and the composition thereof.

Fig. 3 is a graph showing a relationship between the saturation magnetization (Ms) of an Fe-base soft magnetic alloy and the composition thereof.

Fig. 4 is a graph showing X-ray diffraction patterns of the Fe base soft magnetic amorphous alloy, and the cristalline alloy of the present invention.

Fig. 5 is a graph showing the temperature dependence of the magnetic flux density and the coercive force of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 6 is a graph showing the temperature dependence of the effective magnetic permeability of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 7 is a graph showing the temperature dependence of the iron loss of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 8 is a graph showing the temperature dependence of the crystal particle size and the lattice constant of a bcc crystal of an Fe base soft magnetic alloy of the present invention.

Fig. 9 is a graph showing the temperature dependence of the saturation magnetostriction of an Fe base soft magnetic alloy of the present invention.

Fig. 10 is a graph showing the frequency characteristic of the effective magnetic permeability of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 11 is a graph showing the frequency characteristic of the iron loss of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 12 is a graph showing the magnetic flux density dependence of the iron loss of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 13 is a graph showing the frequency characteristic of the effective magnetic permeability of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 14 is a graph showing the frequency characteristic of the iron loss of a magnetic core of an Fe base soft magnetic alloy of the present invention.

Fig. 15 is a graph showing B-H loop of an Fe base soft magnetic alloy of the present invention before heat-treatment.

Fig. 16 is a graph showing B-H loop of an Fe base soft magnetic alloy of the present invention after heat-treatment.

Fig. 17 is a graph showing X-ray diffraction patterns of the Fe base soft magnetic amorphous alloy, and the cristalline alloy of the present invention.

The Best Mode for Carring the Invention

Examples of the present invention is described hereinafter.

Examples 1-9

A quenched ribbon sample having a width of about 1.0-5 mm and a thickness of about 14-20 μm was formed from a melt containing Fe, Si, Al, B and (Nb)in an argon gas atmosphere of one atmosphere pressure by a single roll method. The sample was then heat-treated for about one hour in the presence of a nitrogen gas and argon gas in the absence of a magnetic field.

Other samples were formed in the same manner as above, except that the composition of Fe, Si, Al, B and Nb was varied as shown in Table 1, and these were heat-treated at an optimum temperature (°C) for about one hour and then cooled in a nitrogen stream. The coercive force Hc (mOe) and the saturation magnetization Ms (emu/g) of the heat-treated samples were measured. In addition, the saturation magnetostriction constant λs ($\times 10^{-6}$) of each sample was measured by a strain gage method. The composition of the alloy was determined by IPC analysis.

The iron loss of each of the thus heat-treated coiled magnetic core samples was determined from an area as surrounded by the alternating current hysteresis loop measured with a digital oscilloscope under the condition of a frequency of 100 kHz and a maximum magnetic flux density of 0.1 T. The permeability (μ) of

each of them was determined by measuring the inductance L with an LCR meter under the condition of a frequency of 100 kHz and an exciting magnetic field of 5 mOe. The results obtained are also shown in Table 1 below.

As comparative samples, $Fe_{78}Si_9B_{13}$ (Comparative Example 1, commercial product) and FeCuSiBNb (Comparative Example 2, Cu-containing Fe-base soft magnetic alloy described in Japanese Patent Application Laid-Open No. 64-79342) were prepared, and the coercive force, saturation magnetization, iron loss and permeability of these samples were also shown in Table 1 below.

Table 1

	Composition	Hc mOe	Ms emu/g	λs ×10-6	Iron Loss W/kg	μ	Particle Size Å
Example1	$Fe_{73}Si_8Al_{10}B_9$	95	165	6.2	100	1000	-
2	$Fe_{71}Si_{10}Al_{10}B_9$	85	136	5.6	80	1500	-
3	$Fe_{67}Si_{12}Al_{12}B_9$	50	110	3.0	65	2000	-
4	$Fe_{69}Si_{14}Al_8B_9$	38	110	2.0	40	4000	340
5	$Fe_{68}Si_{13}Al_8B_9$	75	110	2.2	45	2800	-
6	$Fe_{67}Si_{16}Al_8B_9$	95	99	1.5	70	1700	-
7	$Fe_{68}Si_{14}Al_8B_9Nb_1$	10	96	1.2	25	5400	300
8	$Fe_{67}Si_{14}Al_8B_9Nb_2$	15	92	1.0	18	7200	-
9	$Fe_{66}Si_{14}Al_8B_9Nb_3$	15	88	0.6	10	20000	140
Comp. Example1	$Fe_{78}Si_9B_{13}$	50	167	27	40	6000	-
2	$Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$	15	140	2.3	15	17000	-

As is obvious from the results in Table 1 above, the sample of Example 7 containing Nb as M' had a much lower coercive force value than the other FeSiB samples. The value of the coercive force of the sample of Example 7 is almost same as that of the sample of Comparative Example 2 (15 mOe). The samples of Examples 3 and 4 had magnetic properties, with the exception of permeability and saturation magnetization, comparable or superior to those of FeSiB amorphous alloys of comparative Examples 1 and 2.

The sample of Example 9 had superior magnetic properties as to permeability, iron loss and magnetostriction than those of Comparative Example 1 and 2.

Fig. 2 is a graph showing the composition dependence of the coercive force Hc of various Fe-Si-Al-B alloy samples, in which the compositions as surrounded by the line gave a good soft magnetic characteristic of having a coercive force of not more than 100 mOe.

Fig. 3 is a graph showing the composition dependence of the saturation magnetization Ms of various Fe-Si-Al-B alloy samples, in which a sample ($Fe_{73}Si_8Al_{10}B_9$) having a high saturation magnetization of 165 emu/g was obtained from the composition range having a coercive force Hc of not higher than 100 mOe.

Of these samples, the sample of Example 4 ($Fe_{69}Al_8Si_{14}B_9$) and the sample of Example 7 ($Fe_{68}Al_8Si_{14}B_9Nb_1$) having a smaller coercive force than the conventional FeSiB amorphous alloy sample (Comparative Example 1) were measured with respect to the crystal constant a (A), the crystal particle size D (A), the first crystallization temperature TX_1 (°C) and the second crystallization temperature TX_2 (°C). The data measured are shown in Table 2 below.

Table 2

	TX_1 (°C)	TX_2 (°C)	D (Å)	a (Å)
Examle 4	475	560	340	2.86
7	485	610	300	2.85
Comp. Example 1	493	523	-	-

The Table 2 data show that the ΔT value for the Examples 4 and 7 of the present invention are significantly larger than that of the Comparative Example 2. From the data shown in Table 2 above, it has been confirmed that the alloys of the present invention had crystalline particles of bcc solid solution, having a particle size of approximately 300 Å and consisting mainly of iron, as formed by crystallization to be conducted by heat-treatment.

The first crystallization temperature TX_1 is a temperature at which the Fe-base soft magnetic alloy samples may be produced by the use of a conventional heat-treatment device. Regarding the relationship between the first crystallization temperature TX_1 and the second crystallization temperature TX_2 of these samples, the difference between the two temperatures TX_1 and TX_2 was 95°C in the sample of Example 4 and was 125°C in the sample of Example 7, and in the comparative Example 2 was 30°C. From the data, it is understood that formation of crystals interfering with the soft magnetic property of the alloys may well be retarded by selection of the adequate heat-treatment temperature.

The alloy of Example 9 ($Fe_{66}Si_{14}Al_8Nb_3B_9$), which has especially excellent characteristics of high permeability, low iron loss and low magnetostriction, was investigated and examined in more detail, and the results of the examination are mentioned below.

Precisely, the alloy was formed into a ribbon sample having a width of 2.8 mm and a thickness of 17 μm by a single roll method. X-ray diffraction image of the ribbon sample was obtained, immediately after quenched or after heat-treated in a nitrogen gas atmosphere at 580°C for one hour. Fig. 4 shows the X-ray diffraction curves obtained, in which (a) indicates the quenched sample and shows a halo pattern which is specific to an amorphous alloy, and (b) indicates the heat-treated sample and shows a diffraction peak of specific bcc crystals. Specifically, the pattern (b) gives a peak indicating regular lattice reflection of DO_3 structure in the low angle region.

The ribbon sample of the alloy of Example 9 ($Fe_{66}Si_{14}Al_8Nb_3B_9$) was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 2.8 mm, which was then heat-treated in a nitrogen atmosphere for one hour. The heat-treatment temperature dependence of the magnetic flux density B_{10} (T) and the coercive force Hc (mOe) of the coiled magnetic core sample under an applied magnetic field of 100 e was examined, which is shown in Fig. 5. As is obvious from Fig. 5, the magnetic flux density B10 is approximately 0.7 T in the heat-treatment temperature range of from 550°C to 670°C. Regarding the coercive force Hc, it has the minimum value of 12 mOe at 580°C and increases with elevation of the heat-treatment temperature.

Fig. 6 and Fig. 7 each show the heat-treatment temperature dependence of the effective magnetic permeability μe of the coiled magnetic core sample at various frequency and that of the iron loss (100 KHz, 0.1T) of the same, respectively. From Fig. 6, it is noted that the effective magnetic permeability μe has the maximum value at 580°C in a low frequency region (10 KHz or less) and then gradually decreases with elevation of the heat-treatment temperature in the same region. On the other hand, it is further noted that in a high frequency region (100 KHz or more), the temperature of giving the maximum value of the effective magnetic permeability is shifted to a high temperature side with elevation of the frequency. From Fig. 7, it is noted that the iron loss is satisfactorily low or is almost 10 W/g or so in the heat-treatment temperature range of from 580°C to 670°C.

Regarding the alloy of Example 9 as heat-treated for one hour in a nitrogen gas atmosphere, Fig. 8 shows the heat-treatment temperature dependence of the crystal particle size D_{110} (Å) as derived from the half-value width of the (110) diffraction intensity peak of bcc crystal of the alloy by the use of a Sheller's formula and the heat-treatment temperature dependence of the lattice constant a (Å) as obtained from the (110) diffraction peak of the bcc crystal of the same. As is obvious from Fig. 8, the crystal particle size is always almost 140 A or so, irrespective of elevation of the heat-treatment temperature. On the other hand, however, it is noted that the lattice constant gradually decreases with elevation of the heat-treatment temperature.

Fig. 9 shows the heat-treatment temperature dependence of the saturation magnetostriction constant λs (x 10^{-6}) of the alloy of Example 9 as heat-treated in a nitrogen gas atmosphere for one hour. As is obvious

from Fig. 9, the saturation magnetostriction gradually decreases with elevation of the heat-treatment temperature. In particular, it is noted that the alloy sample shows an almost zero magnetostriction in a heat-treatment temperature range of 600 ° C or higher.

A coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 2.8 mm was made of the alloy of example 9 of the present invention, which was heat-treated at 580 ° C or 600 ° C. Fig. 10 shows the frequency characteristic of the effective magnetic permeability μe of each of the two heat-treated coiled magnetic core samples. It also shows the frequency characteristic of the effective magnetic permeability of alloys of Comparative Example 1 and Comparative Example 2 and a typical Mn-Zn ferrite. From Fig. 10, it is noted that the alloy of the present invention has a larger magnetic permeability value than the conventional amorphous alloy (Comparative Example 1) and Mn-Zn ferrite. In addition, in comparison with the fine crystalline soft magnetic alloy having a good frequency characteristic (Comparative Example 2), it is noted that the alloy of the present invention has a higher effective magnetic permeability in a high frequency region of 100 KHz or more. From the data, it is understood that the alloy of the present invention is a novel fine crystalline soft magnetic alloy having excellent magnetic characteristics in a high frequency region.

Fig. 11 and Fig. 12 each show the frequency dependence (characteristic) and the magnetic flux density dependence, respectively, of the iron loss (W/g) of the Example 9 (580 ° C) coiled magnetic core sample as above. These also show the frequency dependence and the magnetic flux density dependence, respectively, of the iron loss of alloys of Comparative Example 1 and Comparative Example 2 and a typical Mn-Zn ferrite. Regarding the frequency dependence of the iron loss of each sample which is shown in Fig. 11, it is noted that the alloy of the present invention has a smaller iron loss than conventional amorphous alloy, Mn-Zn ferrite and fine crystalline soft magnetic alloy in a frequency range of from 10 KHz to 700 KHz. Regarding the magnetic flux density dependence of the iron loss of each sample which is shown in Fig. 12, it is noted that the alloy of Example 9 (580 ° C) has a smaller iron loss than conventional amorphous alloy, Mn-Zn ferrite and fine crystalline soft magnetic alloy in a magnetic flux density range of from 0.1 T to 0.5 T. These results show that the alloy of the present invention has an excellent magnetic properties compared to the conventional alloy.

Examples 10-25

A amorphous ribbon having a width of about 1.3 mm and a thickness of about 18 μm was formed from a melt containing Fe, Si, Al, B and Nb in an argon gas atmosphere of one atmosphere pressure by a single roll method. The ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 1.3 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, the coercive force Hc (mOe), the saturation magnetostriction constant λs ($\times 10^{-6}$), the effective permeability (μ) (a frequency of 100 KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T) of each core were measured. The composition of the samples and the results obtained are shown in Table 3 below.

Table 3

	Coercive force (mOe)	Saturation Magneization ($\times 10^{-6}$)	Permeability (100KHz,5mOe)	Iron Loss(W/kg) (100KHz,0.1T)	Particle Size (Å)
Example10	46	1.8	4000	52	160
11	36	1.5	3400	50	155
12	26	0.6	5600	30	145
13	22	0.5	3100	50	135
14	46	1.0	5400	30	160
15	30	1.1	8300	17	150
16	28	0.5	8600	20	145
17	16	0.2	8000	22	130
18	25	0.5	8600	22	160
19	28	0.1	9100	20	140
20	40	~0	8000	17	155
21	28	0.3	4400	28	165
22	26	0.1	9400	16	150
23	40	-0.2	4300	30	155
24	28	0.4	4400	28	160
25	42	-0.8	2200	50	165

Example 10	$Fe_{69}Si_{12}Al_7Nb_3B_9$
Example 11	$Fe_{68}Si_{12}Al_8Nb_3B_9$
Example 12	$Fe_{67}Si_{12}Al_9Nb_3B_9$
Example 13	$Fe_{66}Si_{12}Al_{10}Nb_3B_9$
Example 14	$Fe_{68}Si_{13}Al_7Nb_3B_9$
Example 15	$Fe_{67}Si_{13}Al_8Nb_3B_9$
Example 16	$Fe_{66}Si_{13}Al_9Nb_3B_9$
Example 17	$Fe_{65}Si_{13}Al_{10}Nb_3B_9$
Example 18	$Fe_{67}Si_{14}Al_7Nb_3B_9$
Example 19	$Fe_{65}Si_{14}Al_9Nb_3B_9$
Example 20	$Fe_{64}Si_{14}Al_{10}Nb_3B_9$
Example 21	$Fe_{66}Si_{15}Al_7Nb_3B_9$
Example 22	$Fe_{65}Si_{15}Al_8Nb_3B_9$
Example 23	$Fe_{64}Si_{15}Al_9Nb_3B_9$
Example 24	$Fe_{65}Si_{16}Al_7Nb_3B_9$
Example 25	$Fe_{64}Si_{16}Al_8Nb_3B_9$

As is obvious from the results in Table 3 above, the alloy of the example 10-25 including no Ni shows very low magnetostriction in the range of 7-10 atomic % of the Al content.

Examples 26-39 Comparative Example 3

A amorphous ribbon having a width of about 2.8 mm and a thickness of about 18 μm was formed by the same process of example 10 and the ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 2.8 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, the effective permeability (μ) (a frequency of 100

KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T) of each core were measured. The composition of the samples and the results obtained are shown in Table 4 below.

Table 4

	Composition (atom%)	Permeability μ (100KHz,5mOe)	Iron Loss(W/kg) (100KHz,0.1T)
Example 26	$Fe_{65.5}Si_{14}Al_8Nb_3B_{9.5}$	14000	12
27	$Fe_{65}Si_{14}Al_8Nb_{3.5}B_{9.5}$	19000	9
28	$Fe_{65}Si_{13.9}Al_{7.8}Nb_{3.3}B_{10}$	20000	10
29	$Fe_{64}Si_{14}Al_8Nb_4B_{10}$	17000	10
30	$Fe_{64}Si_{13.5}Al_{7.5}Nb_4B_{11}$	12000	12
31	$Fe_{65}Si_{14}Al_8Nb_4B_{9.5}$	16000	14
32	$Fe_{69}Si_{13}Al_4Nb_4B_{10}$	7000	22
33	$Fe_{67}Si_{13}Al_6Nb_4B_{10}$	12000	16
34	$Fe_{63.7}Si_{13}Al_{10}Nb_{3.3}B_{10}$	14000	9
35	$Fe_{61}Si_{13}Al_{12}Nb_4B_{10}$	10000	16
36	$Fe_{63.5}Si_{13}Al_{7.5}Nb_4B_{12}$	9000	18
37	$Fe_{60}Si_{12.8}Al_{7.2}Nb_6B_{14}$	7800	20
38	$Fe_{61}Si_{16}Al_9Nb_4B_{10}$	5000	34
39	$Fe_{58}Si_{18}Al_{10}Nb_4B_{10}$	4200	46

As is obvious from the results in Table 4 above, the alloy including more than 9 atomic % of B shows a low iron loss and a high permeability.

Examples 40-59

A amorphous ribbon having a width of about 1.3 mm and a thickness of about 18 μm was formed from a melt containing Fe, Si, Al, B, and M' in an argon gas atmosphere of one atmosphere pressure by a single roll method. The ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 1.3 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, the coercive force Hc (mOe), the permeability (μ) (a frequency of 100 KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T)of each core were measured. The composition of the samples and the results obtained are shown in Table 5 below.

Table 5

	Coercive Force (mOe)	Permeability (100KHz,5mOe)	Iron Loss(W/kg) (100KHz,0.1T)
Example 40	26	13800	15
41	56	13200	12
42	18	4000	40
43	22	5000	30
44	28	6000	24
45	20	14000	15
46	50	4200	40
47	22	11000	18
48	24	11000	15
49	28	5000	26
50	20	12000	18
51	28	8000	24
52	28	8200	22
53	32	11000	18
54	26	9000	20
55	26	8000	28
56	30	8000	32
57	28	7000	30
58	46	6000	26
59	42	5200	42

Example 40	$Fe_{66}S_{14}Al_8Mo_3B_9$
41	$Fe_{66}Si_{14}Al_8Ta_3B_9$
42	$Fe_{66}Si_{14}Al_8Cr_3B_9$
43	$Fe_{66}Si_{14}Al_8V_3B_9$
44	$Fe_{66}Si_{14}Al_8Ti_3B_9$
45	$Fe_{66}Si_{14}Al_8W_3B_9$
46	$Fe_{66}Si_{14}Al_8Mn_3B_9$
47	$Fe_{66}Si_{14}Al_8Hf_3B_9$
48	$Fe_{66}Si_{14}Al_8Zr_3B_9$
49	$Fe_{66}Si_{14}Al_8Y_3B_9$
50	$Fe_{64}Si_{14}Al_8Nb_2Mo_2B_{10}$
51	$Fe_{62}Si_{13}Al_8Nb_3Ta_2B_{12}$
52	$Fe_{63}Si_{13}Al_8Nb_3Zr_1B_{12}$
53	$Fe_{65}Si_{13}Al_8Mo_2W_2B_{10}$
54	$Fe_{63}Si_{13}Al_7Nb_4Pd_3B_{10}$
55	$Fe_{63}Si_{13}Al_6Nb_4Ru_4B_{10}$
56	$Fe_{66}Si_{14}Al_4Ga_4Nb_4B_{10}$
57	$Fe_{66}Si_{14}Al_6Ge_3Nb_4B_{10}$
58	$Fe_{61}Si_{14}Al_8Zr_4B_9C_4$
59	$Fe_{63}Si_{14}Al_6Zr_4B_{10}P_3$

As is obvious from the results in Table 5 above, both amorphous alloys including an other element than Nb as M'(examples 40-49, 53, 53 and 59) and alloys including the element together with Nb show excellent magnetic characteristics.

Examples 60-66

A amorphous ribbon having a width of about 1.3 mm and a thickness of about 18 μm was formed by the same process of example 10 and the ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 1.3 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, the effective permeability (μ) (a frequency of 100 KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T) of each core were measured. The composition of the samples and the results obtained are shown in Table 6 below.

Table 6

	Composition (atom%)	Permeability μ (100KHz)	Iron Loss(W/kg) (100KHz,0.1T)
Example 60	$Fe_{75}Si_8Al_5Nb_3B_9$	3400	40
61	$Fe_{74}Si_9Al_5Nb_3B_9$	4600	37
62	$Fe_{74}Si_8Al_6Nb_3B_9$	2600	46
63	$Fe_{73}Si_{10}Al_5Nb_3B_9$	2000	58
64	$Fe_{71}Si_9Al_6Nb_4B_{10}$	5100	32
65	$Fe_{69.7}Si_{8.6}Al_{5.7}Nb_4B_{12}$	5000	36
66	$Fe_{66}Si_8Al_5Nb_5B_{16}$	1000	100

Examples 67-81

A amorphous ribbon having a width of about 2.8 mm and a thickness of about 18 μm was formed by the same process of example 10 and the ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 2.8 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, the effective permeability (μ) (a frequency of 100

KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T) of each core were measured. The composition of the samples and the results obtained are shown in Table 7 below.

Table 7

	Before Heat-treatment		After Heat-treatme		Particle Size Å
	In the Presence of a Magnetic Field				
	Permeability (100KHz,5mOe)	Iron Loss (W/Kg) (100KHz,0.1T)	Permeability (100KHz,5mOe)	Iron Loss (W/Kg) (100KHz,0.1T)	
Example67	9000	20	10000	14	140
68	13000	13	14000	9	140
69	13000	12	10000	9	140
70	13000	12	9000	8	140
71	6000	30	5000	18	150
72	8000	25	9000	15	-
73	10000	20	9000	15	150
74	11000	18	9400	12	150
75	10000	16	9000	12	150
76	9800	20	9600	16	-
77	9600	18	8800	12	-
78	9400	16	9000	12	-
79	8600	18	8600	14	-
80	8400	18	8600	14	-
81	8600	20	8800	16	-

Example 67	$Fe_{66}Ni_{1.6}Si_{14}Al_{6.4}Nb_3B_9$
68	$Fe_{66}Ni_{3.2}Si_{14}Al_{4.8}Nb_3B_9$
69	$Fe_{66}Ni_4Si_{14}Al_4Nb_3B_9$
70	$Fe_{66}Ni_{4.8}Si_{14}Al_{3.2}Nb_3B_9$
71	$Fe_{66}Ni_{5.5}Si_{14}Al_{2.5}Nb_3B_9$
72	$Fe_{69.4}Ni_{2.4}Si_{9.6}Al_{6.6}Nb_3B_9$
73	$Fe_{66}Ni_{2.8}Si_{11.2}Al_8Nb_3B_9$
74	$Fe_{65}Ni_4Si_{14}Al_4Nb_{3.5}B_{9.5}$
75	$Fe_{65}Ni_{4.8}Si_{14}Al_{3.2}Nb_{3.5}B_{9.5}$
76	$Fe_{64}Ni_4Si_{14}Al_4Nb_4B_{10}$
77	$Fe_{64.5}Ni_{4.8}Si_{13.5}Al_{3.2}Nb_4B_{10}$
78	$Fe_{64}Ni_4Si_{13}Al_4Nb_4B_{11}$
79	$Fe_{63}Ni_{4.8}Si_{13}Al_{3.2}Nb_4B_{12}$
80	$Fe_{62}Ni_{4.5}Si_{13}Al_4Nb_{4.5}B_{12}$
81	$Fe_{59}Ni_4Si_{13}Al_4Nb_6B_{14}$

As is obvious from the results in Table 7 above, the alloy of these examples shows an excellent value of an iron loss as well as a permeability.

Further, the frequency dependence of the effect permeability (μ) and the iron loss of the Example 69 (O) which was heat-treated in the absence of a magnetic field was measured. At the same time, the frequency dependence of the effect permeability (μ) and the iron loss of the Example 69 (●) which was

heat-treated in the presence of a magnetic field was measured. The results obtained are shown in Figs. 13 and 14. B-H loops in the exciting magnetic field (Hm) of 100 e, 10 e and 0.10 e are also illustrated in Figs. 15 and 16.

As is obvious from Fig. 13, the alloy of the present invention showed a high permeability in the high frequency range of 100 kHz or more by heat-treating in the presence of a magnetic field. Particularly in the range of 200 kHz or more, the alloy of the present invention showed higher permeability than that (Δ) of the ribbon (a comparative example 2, a width of 5 mm and a thickness of 18 μm) of a soft magnetic alloy having a good frequency characteristic which was heat-treated in the presence of a magnetic field.

As is obvious from Fig. 14, the iron loss of the alloy of the present invention was sharply reduced by heat-treating in the presence of a magnetic field. The value of the iron loss is lower than that (Δ) of the ribbon (a comparative example 2, a width of 5 mm and a thickness of 18 μm) which was heat-treated in the presence of a magnetic field.

Further, as is obvious from comparison of B-H loop of the pre-heat-treated alloy and that of the heat-treated alloy, the alloy of the present invention showed excellent soft magnetic properties by heat-treatment in the presence of a magnetic field. X-ray diffraction image of Example 69 which was heat- treated for one hour in a nitrogen atmosphere is shown in Fig. 17.

Examples 82-86

A amorphous ribbon (Fe-Co-Si-Al-Nb-B) having a width of about 2.8 mm and a thickness of about 18 μm was formed by the same process of example 10 and the ribbon of the alloy was formed into a coiled magnetic core having an inner diameter of 15 mm, an outer diameter of 19 mm and a height of 2.8 mm. After the coiled core was optimum heat-treated in the absence of a magnetic field, further heat-treated in the presence of a magnetic field. The permeability (μ) (a frequency of 100 KHz, an exciting magnetic field of 5mOe) and the iron loss (a frequency of 100 KHz, a maximum magnetic flux density of 0.1T) of both pre-heat-treated core and a heat-treated core in a magnetic field were measured. The composition of the alloy and the results obtained are shown in Table 8 below.

Table 8

	Before Heat-treatment		After Heat-treatment	
	In the Presence of a Magnetic Field			
	Iron Loss (W/Kg) (100KHz,0.1T)	Permeability (100KHz,5mOe)	Iron Loss (W/Kg) (100KHz,0.1T)	Permeability (100KHz,5mOe)
Example 82	18	11000	13	12000
83	16	7100	14	7200
84	28	3900	24	3800
85	57	2800	48	2800
86	30	5100	25	6000

Example 82	$Fe_{66}Co_{1.6}Si_{14}Al_{6.4}Nb_3B_9$
83	$Fe_{66}Co_{3.2}Si_{14}Al_{4.8}Nb_3B_9$
84	$Fe_{66}Co_4Si_{14}Al_4Nb_3B_9$
85	$Fe_{66}Co_{2.8}Si_{11.2}Al_8Nb_3B_9$
86	$Fe_{66}Co_{5.6}Si_{8.4}Al_8Nb_3B_9$

As is obvious from the results in Table 8 above, the alloy including Co instead of Ni shows as low iron loss as that including Ni, whereas some examples having Co show a lower permeability than the latter.

The content of crystal (fine crystalline particles) is 60 % or more in the alloy of the all examples above.

Capabilityof Exploitation in Industry

As is obvious from the results in the above-mentioned examples, the present invention provides a novel Fe-base soft magnetic alloy as prepared by adding Al to an Fe-Si-B alloy composition, and the alloy has excellent soft magnetic properties. In addition, since the Fe-base soft magnetic alloy of the present invention has a large temperature difference between the crystallization temperature of crystals of showing a good soft magnetic property and the crystallization temperature of crystals of interfering with a soft magnetic property, the range of the temperature of heat treatment is sufficiently wider than that of the conventional amorphous alloys.

The Fe-base soft magnetic alloy of the present invention shows a very low magnetostriction by adding Al thereto and at the same time substituting Ni (Co) for a part of Fe, whereby a magnetic core having a low iron loss can be obtained.

Furthermore, in accordance with the present invention, Nb or the like element may be added to an Fe-Si-Al-B alloy composition to give a novel Fe-base soft magnetic alloy having excellent soft magnetic properties, especially having an extremely low coercive force, low iron loss and low magnetostriction as well as a high permeability in a high frequency region.

Since the alloy of the present invention possesses excellent properties as above-mentioned, it is useful for such applications as (material for magnetic core of) a high-frequency transformer, a common-mode choke coil, a magnetic amplifier, an inductor for filters, a transformer for signals, a magnetic head and so on.

Claims

1. An Fe-base soft magnetic alloy having a composition as represented by the general formula:

$$(Fe_{1-x}M_x)_{100-a-b-c-d}Si_aAl_bB_cM'_d$$

where M is Co and/or Ni;
M' is at least one element selected from the group consisting of Nb, Mo, Zr, W, Ta, Hf, Ti, V, Cr, Mn, Y, Pd, Ru, Ga, Ge, C and P;
x is an atomic ratio;
a, b, c and d each are an atomic %; and
x, a, b, c and d each satisfy $0 \leq x \leq 0.15$, $0 \leq a \leq 24$, $2 < b \leq 15$, $4 \leq c \leq 20$, and $0 \leq d \leq 10$.

2. The Fe-base soft magnetic alloy as claimed in claim 1, in which at least 30 % of the alloy structure is occupied by a crystalline phase with the balance being an amorphous phase.

3. The Fe-base soft magnetic alloy as claimed in claim 2, in which the crystalline phase is bcc solid solution consisting mainly of iron.

4. The Fe-base soft magnetic alloy as claimed in claim 1, in which M' is Nb.

5. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content(x) of M is $x = 0$.

6. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (x) of M is $0.02 \leq x \leq 0.15$.

7. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (x) of M is $0.03 \leq x \leq 0.1$.

8. The Fe-base soft magnetic alloy as claimed in claim 1, in which M is Ni.

9. The Fe-base soft magnetic alloy as claimed in claim 6, in which M is Ni.

10. The Fe-base soft magnetic alloy as claimed in claim 7, in which M is Ni.

11. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (b) of Al is $2.5 \leq b \leq 15$.

12. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (b) of Al is $3 \leq b \leq 12$.

13. The Fe-base soft magnetic alloy as claimed in claim 8, in which the content (b) of Al is $3 \leq b \leq 10$.

14. The Fe-base soft magnetic alloy as claimed in claim 5, in which the content (b) of Al is $7 \leqq b \leqq 12$.

15. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (c) of B is $6 \leqq c \leqq 15$.

16. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (c) of B is $9.5 \leqq c \leqq 15$.

17. The Fe-base soft magnetic alloy as claimed in claim 1, in which the content (c) of B is $10 \leqq c \leqq 14$.

Fig. 1

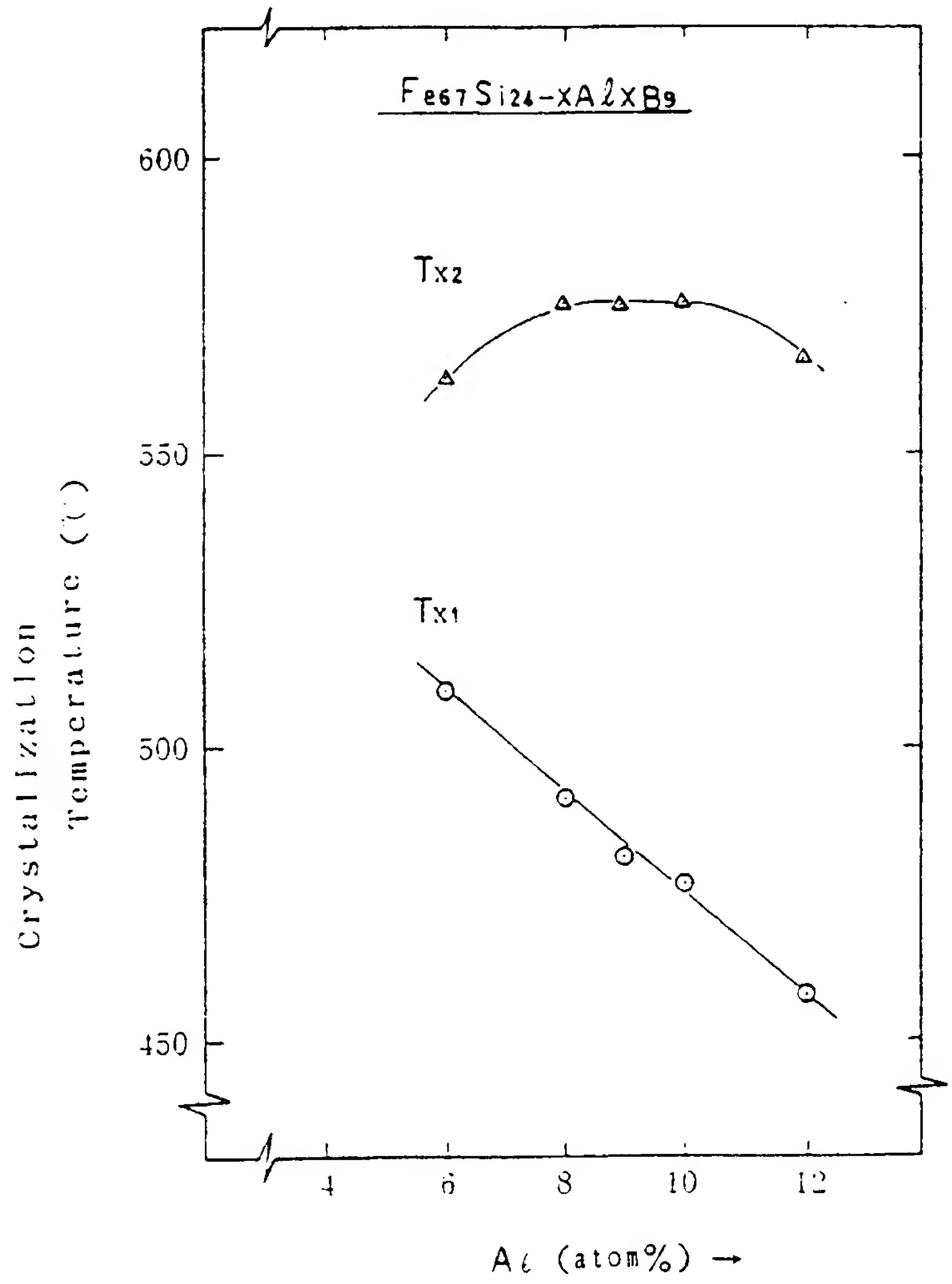

$Fe_{67}Si_{24-x}Al_xB_9$
Tx2
Tx1
600
550
500
450
4
6
8
10
12
Crystallization Temperature (℃)
Al (atom%) →

Fig. 2

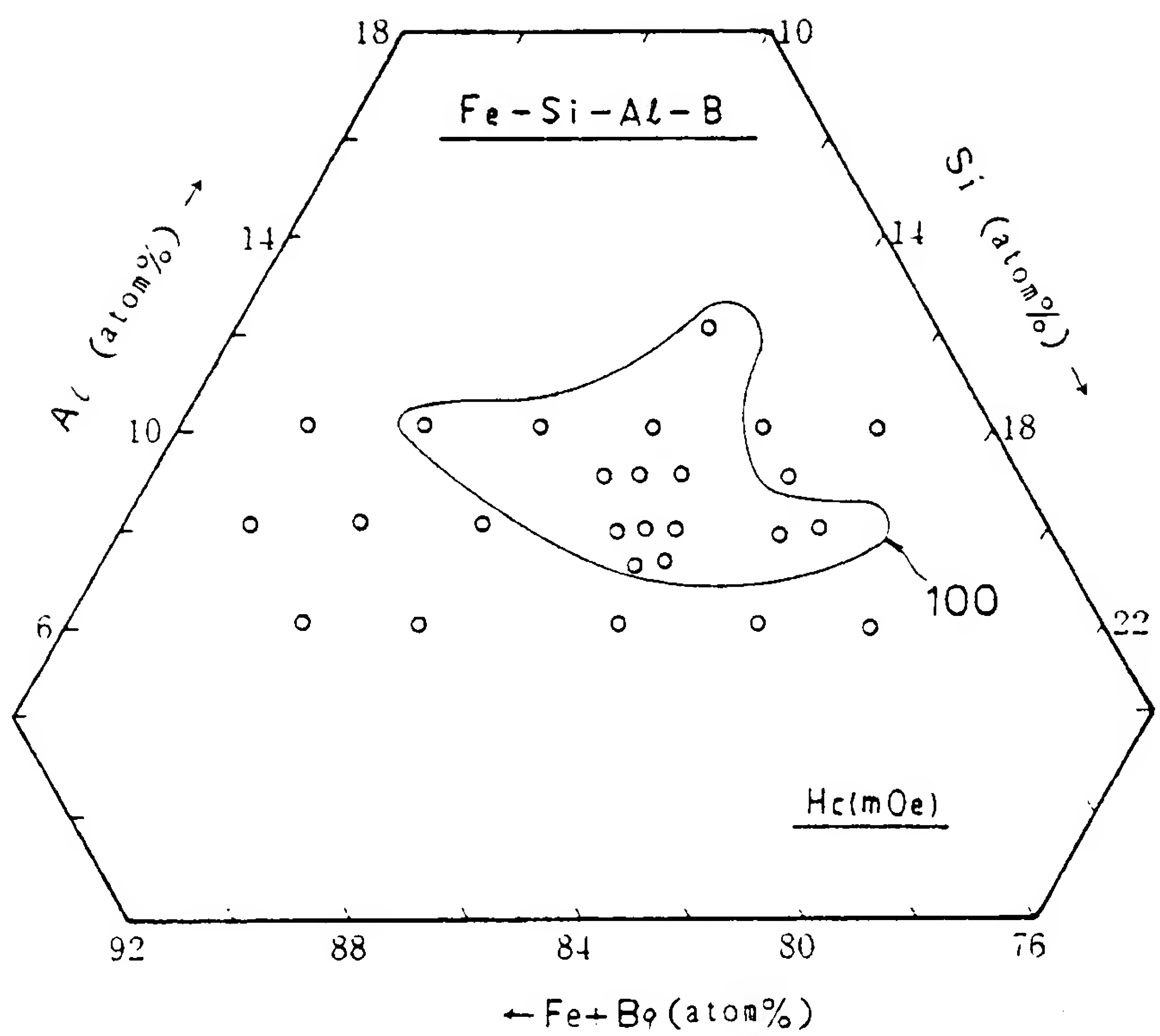

Fe-Si-Al-B
Al (atom%)
Si (atom%)
18
14
10
6
10
14
18
22
100
Hc(mOe)
92
88
84
80
76
← Fe+Bq (atom%)

Fig.3

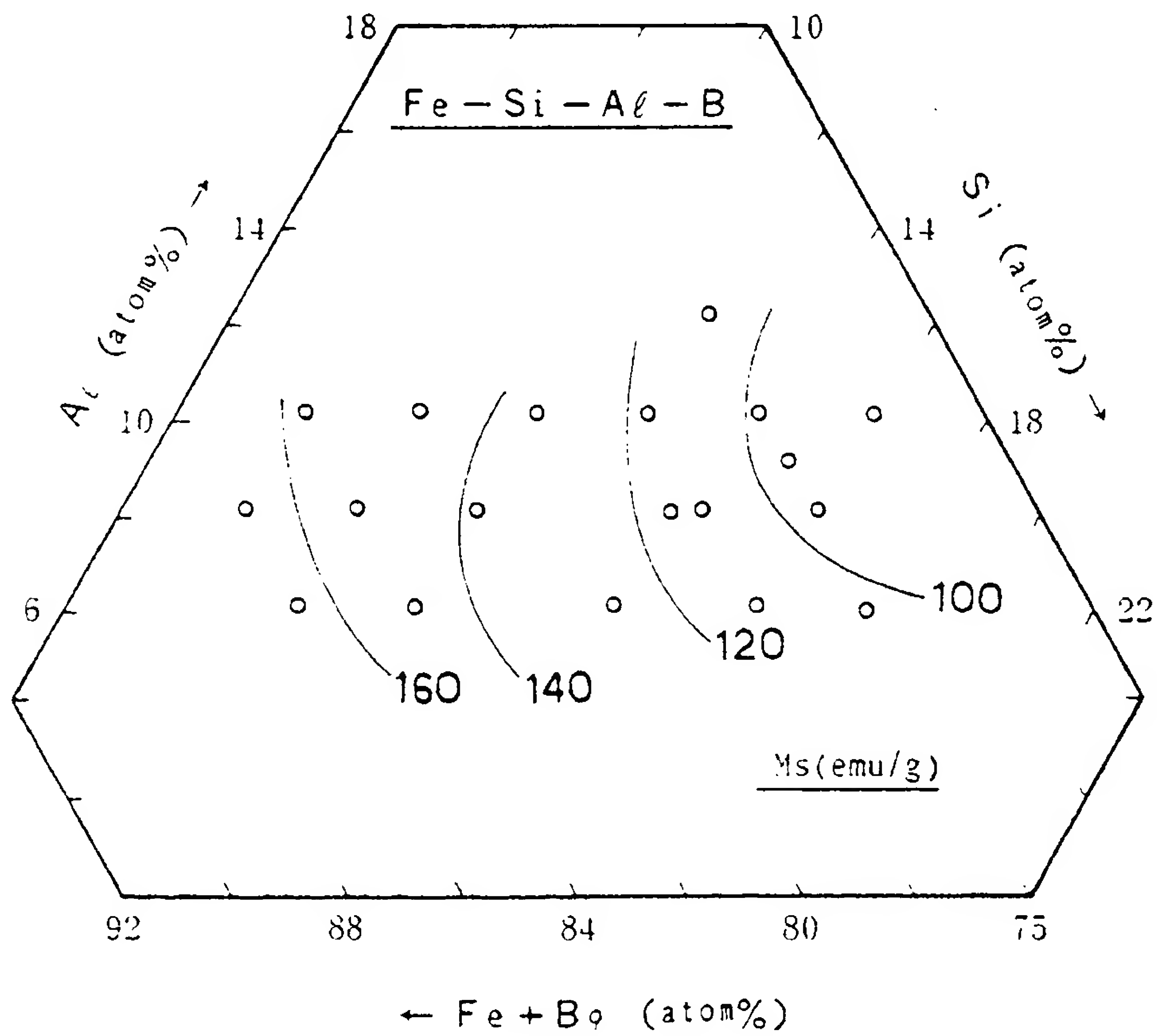

Fe − Si − Aℓ − B
18
10
14
14
10
18
6
22
Aℓ (atom%) →
Si (atom%) →
160
140
120
100
Ms(emu/g)
92
88
84
80
75
← Fe + B9 (atom%)

Fig. 4

(a)

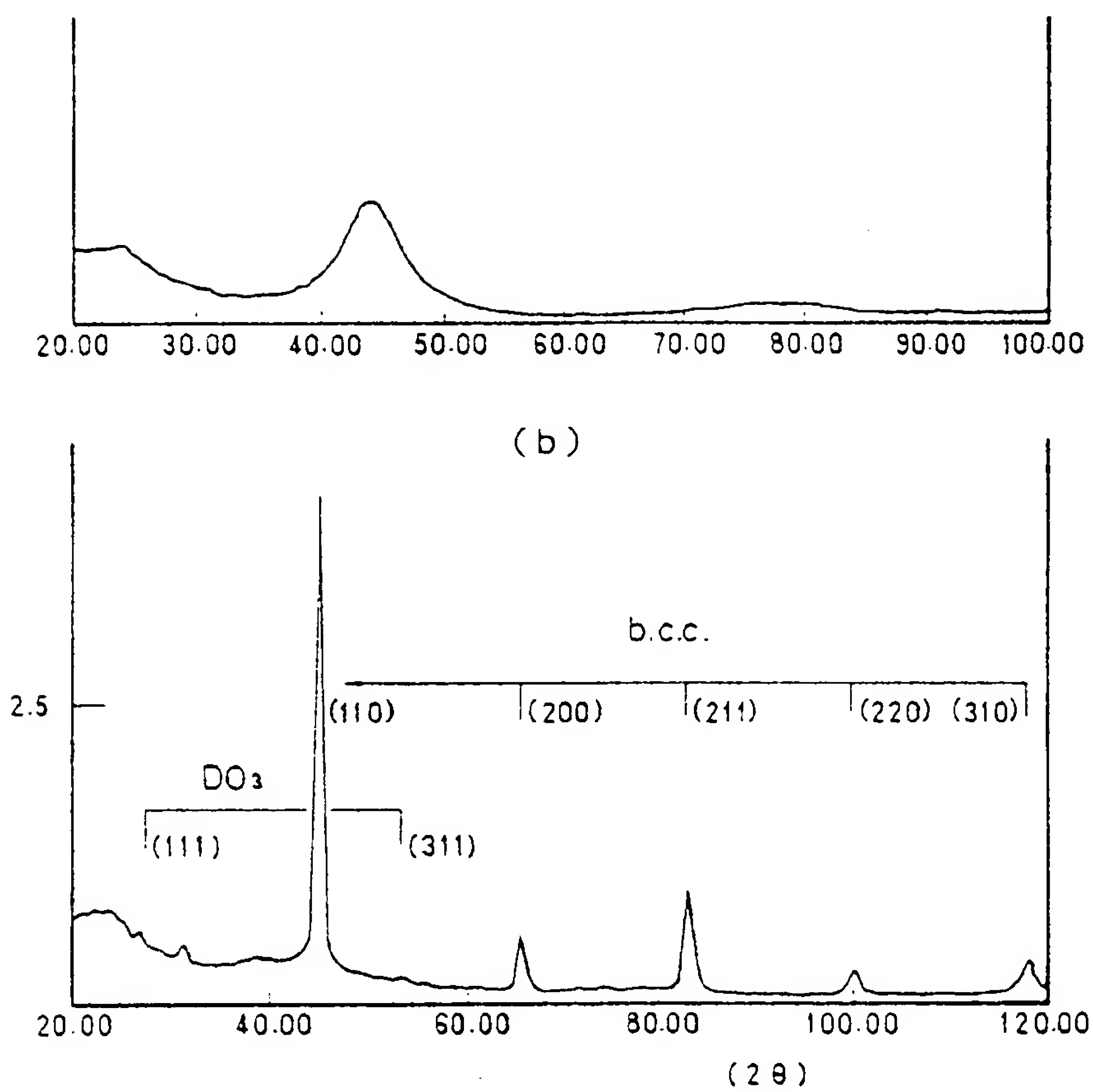

20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
(b)
b.c.c.
2.5
(110)
(200)
(211)
(220)
(310)
DO3
(111)
(311)
20.00
40.00
60.00
80.00
100.00
120.00
(2θ)

Fig. 5

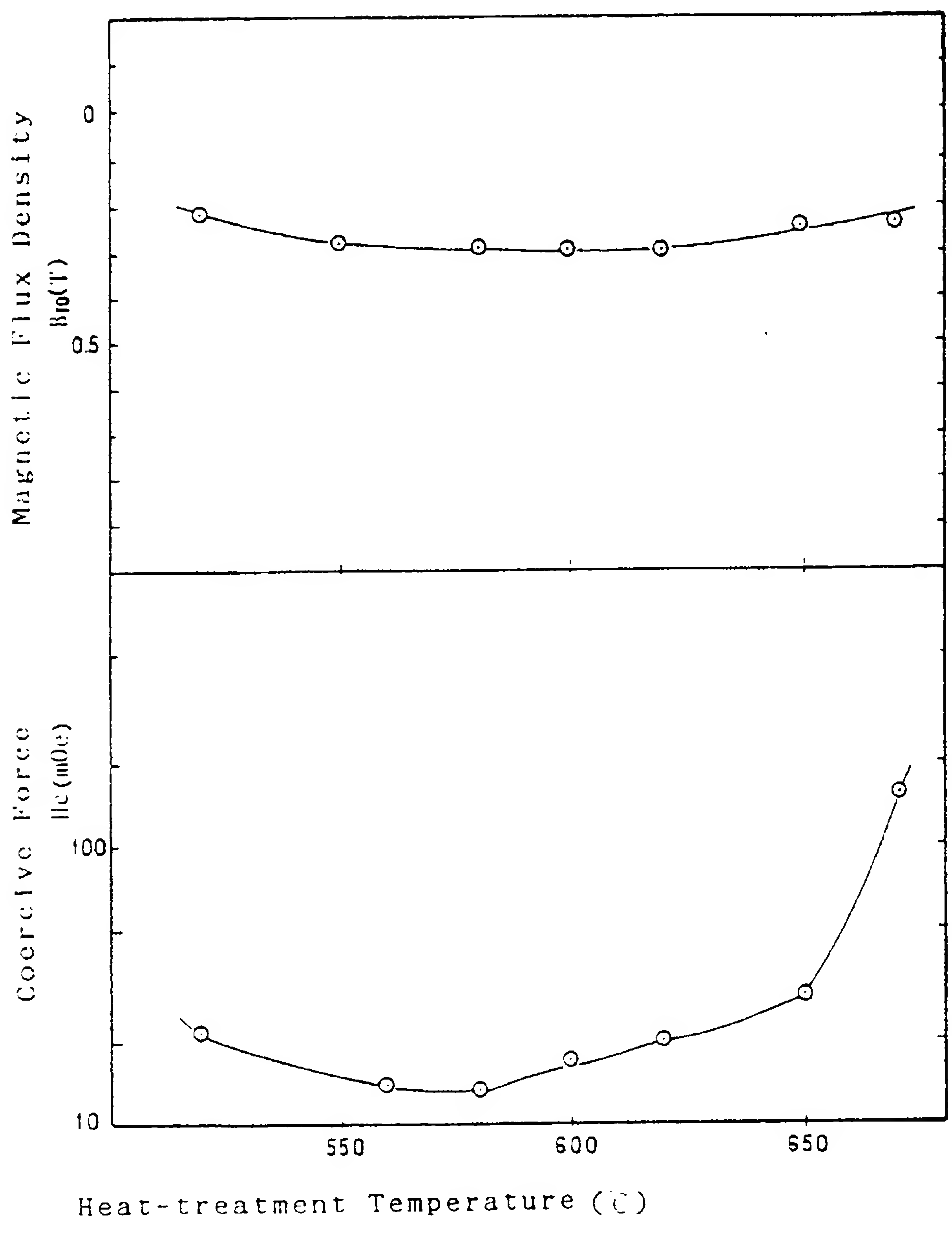

Magnetic Flux Density
B_{10}(T)
0
0.5
Coercive Force
Hc(mOe)
100
10
550
600
650
Heat-treatment Temperature (℃)

Fig. 6

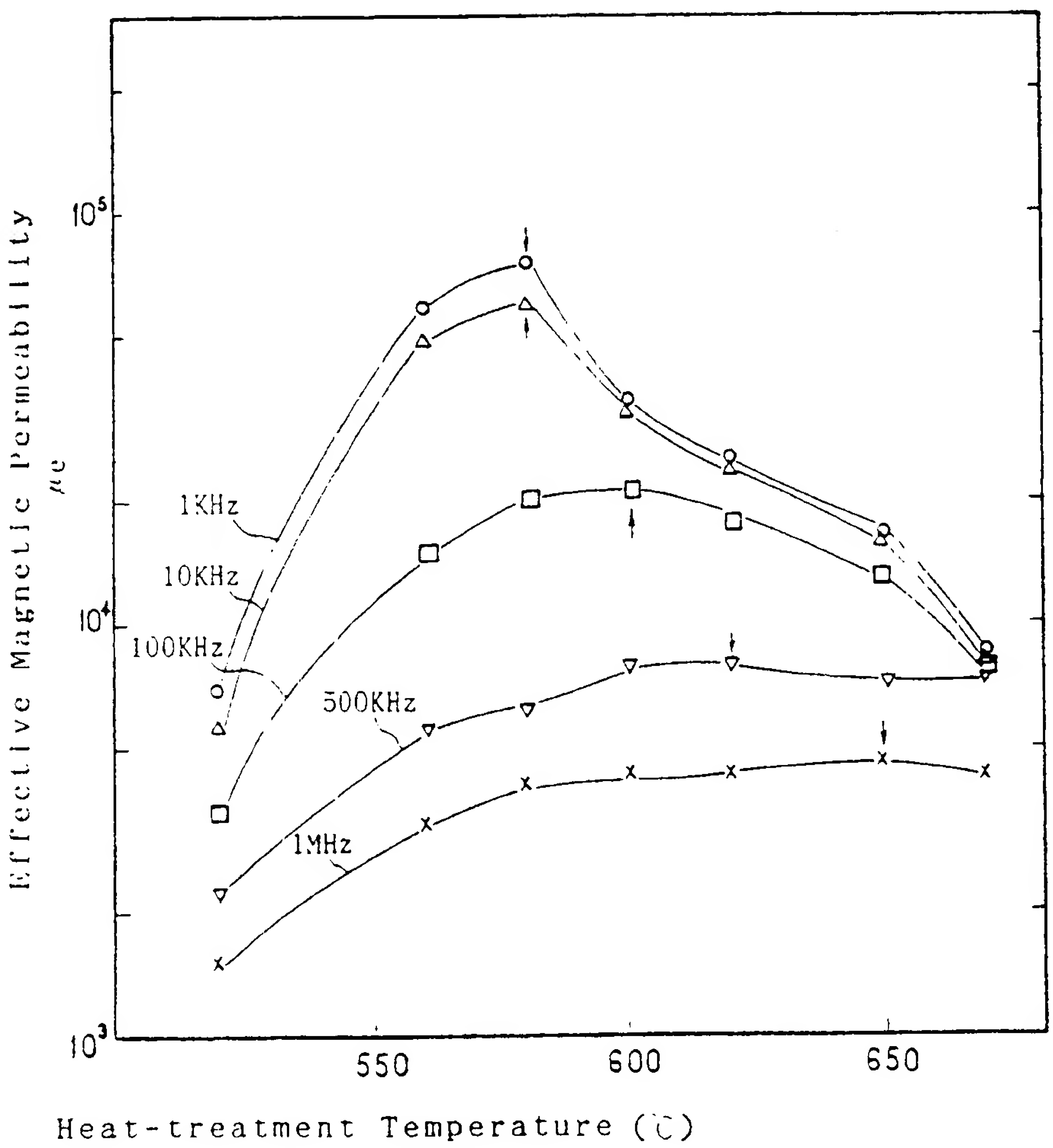

Effective Magnetic Permeability μe
10^5
10^4
10^3
1KHz
10KHz
100KHz
500KHz
1MHz
550
600
650
Heat-treatment Temperature (℃)

Fig. 7

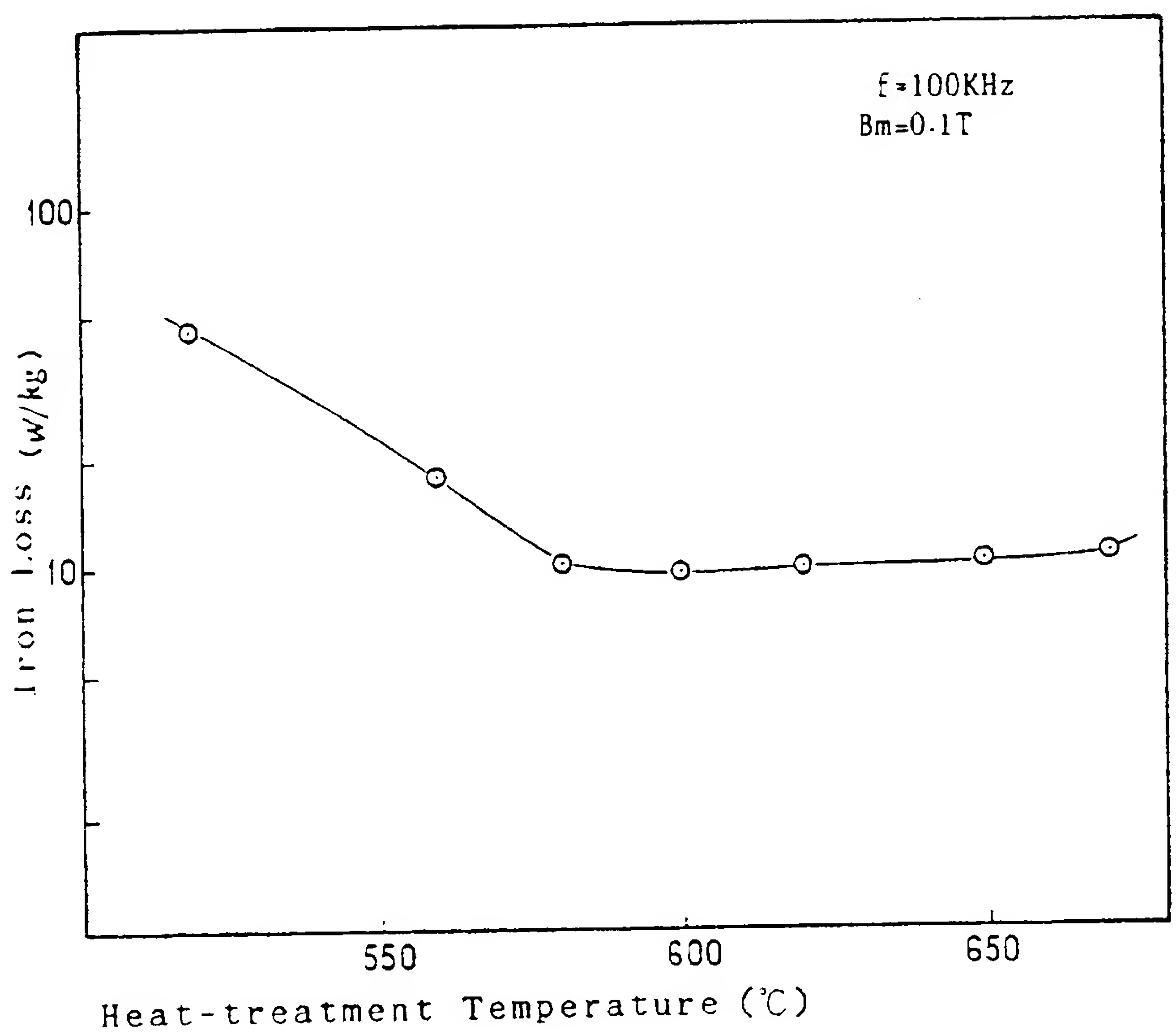

f=100KHz
Bm=0.1T
100
10
Iron Loss (w/kg)
550
600
650
Heat-treatment Temperature (℃)

Fig. 8

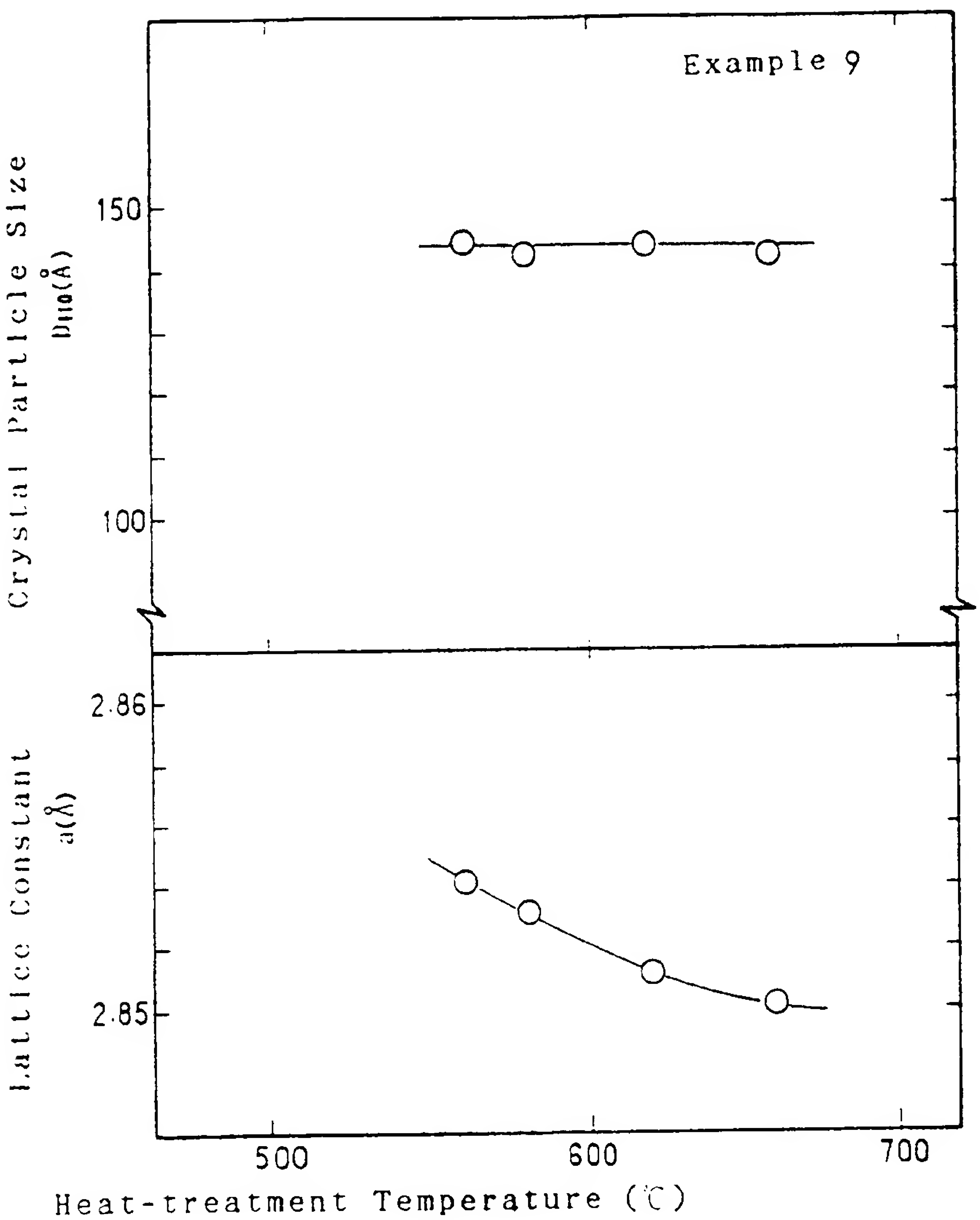

Example 9
Crystal Particle Size
D_{110}(Å)
150
100
Lattice Constant
a(Å)
2.86
2.85
500
600
700
Heat-treatment Temperature (℃)

Fig. 9

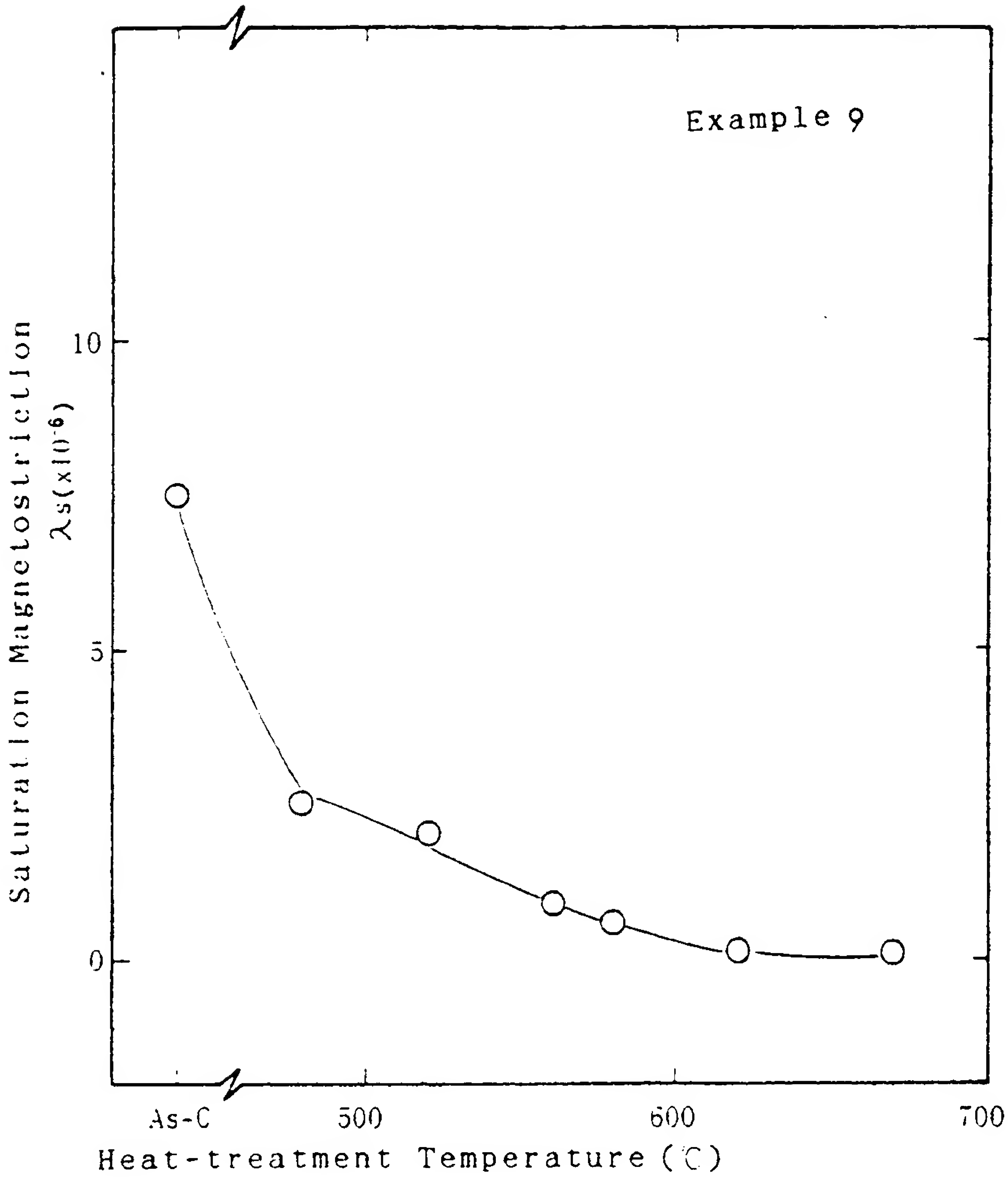

Example 9
Saturation Magnetostriction
λs(x10⁻⁶)
10
5
0
As-C
500
600
700
Heat-treatment Temperature (℃)

Fig. 10

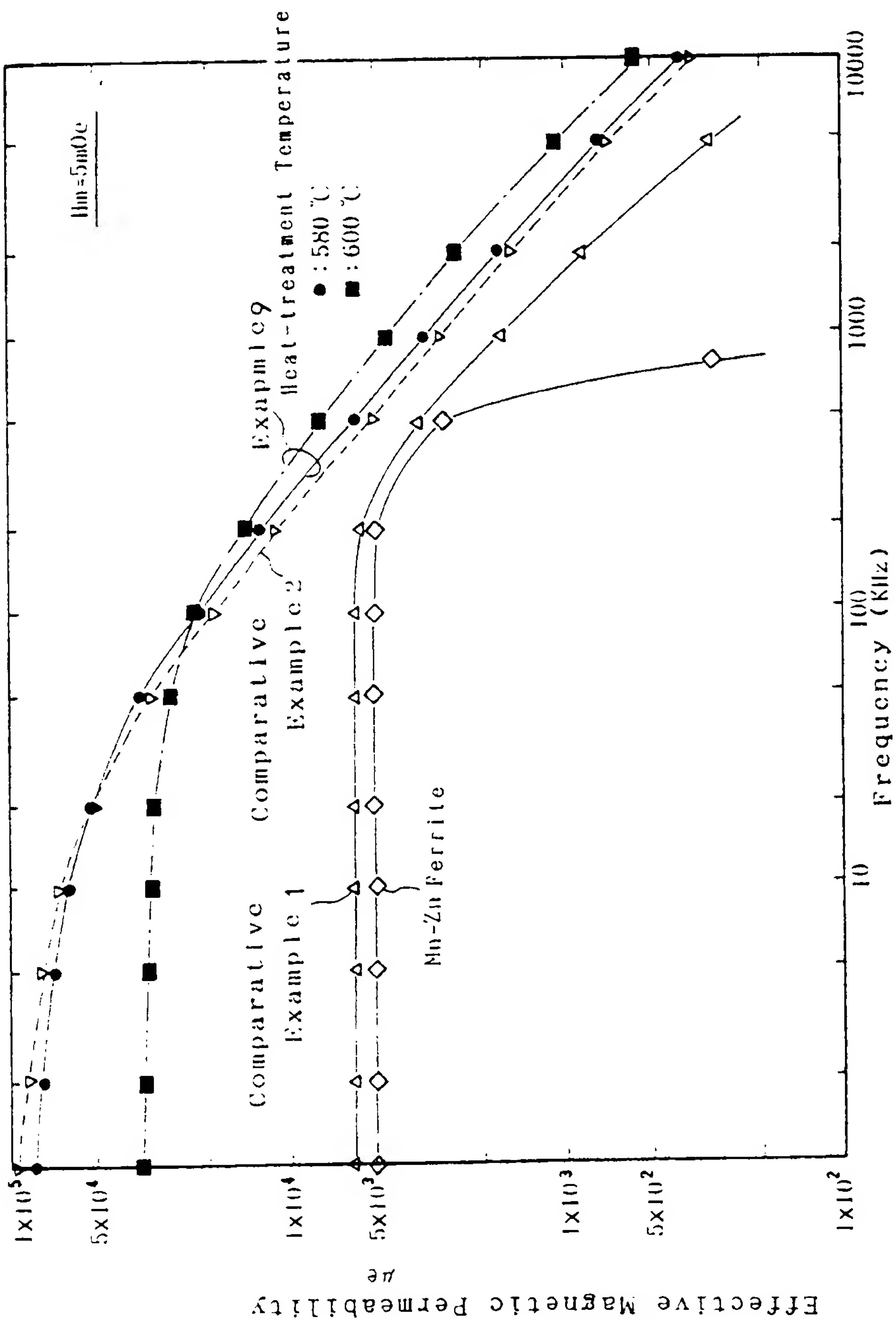

Hm=5mOe
Exapmle9
Heat-treatment Temperature
●: 580 ℃
■: 600 ℃
Comparative Example 2
Comparative Example 1
Mn-Zn Ferrite
Frequency (KHz)
10
100
1000
10000
Effective Magnetic Permeability
μe
1x10^5
5x10^4
1x10^4
5x10^3
1x10^3
5x10^2
1x10^2

Fig. 11

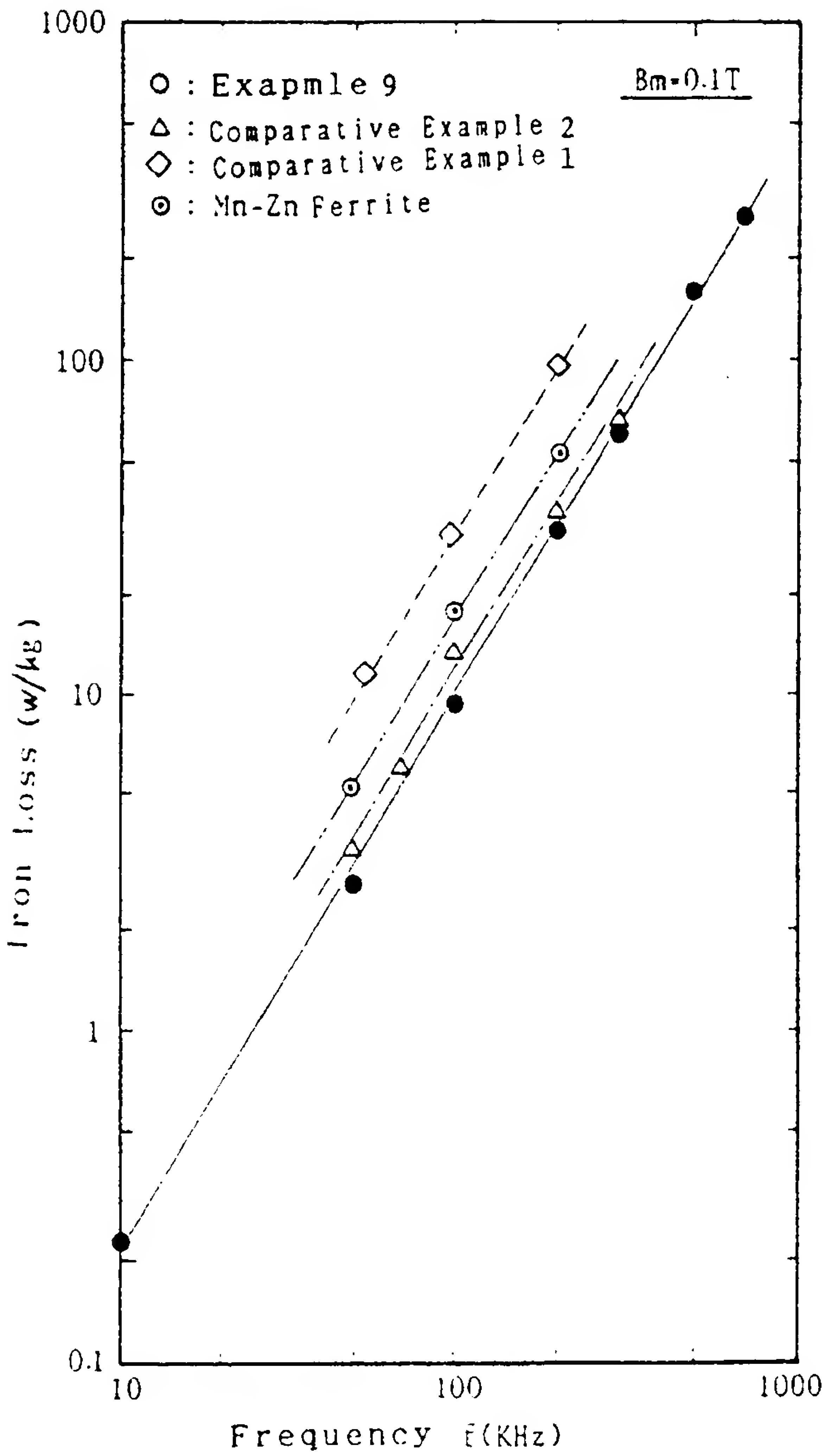

○ : Exapmle 9
△ : Comparative Example 2
◇ : Comparative Example 1
⊙ : Mn-Zn Ferrite
Bm=0.1T
1000
100
10
1
0.1
10
100
1000
Iron Loss (w/kg)
Frequency f(KHz)

Fig. 12

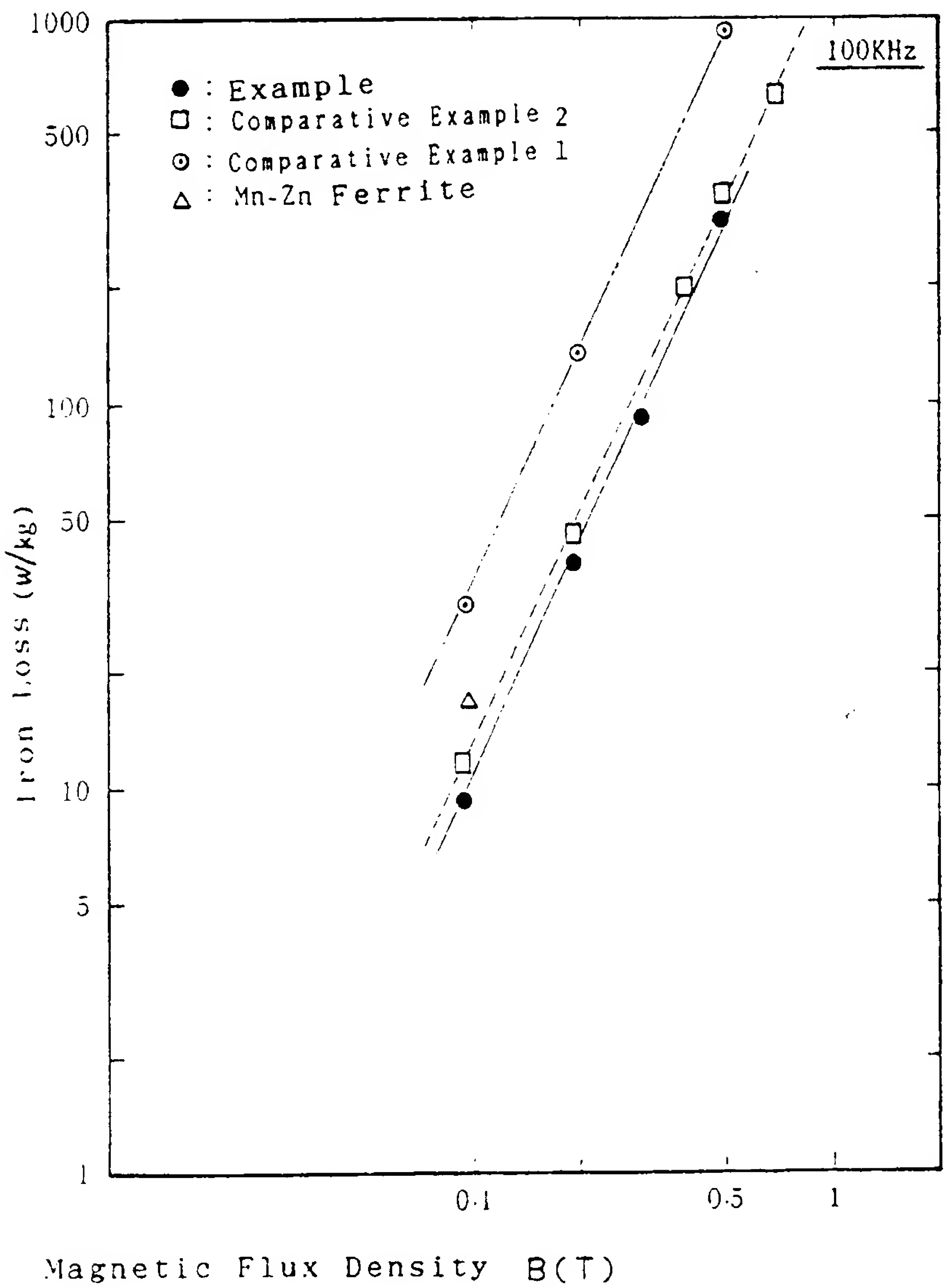

1000
500
100
50
10
5
1
100KHz
● : Example
□ : Comparative Example 2
⊙ : Comparative Example 1
△ : Mn-Zn Ferrite
Iron Loss (w/kg)
0.1
0.5
1
Magnetic Flux Density B(T)

Fig. 12

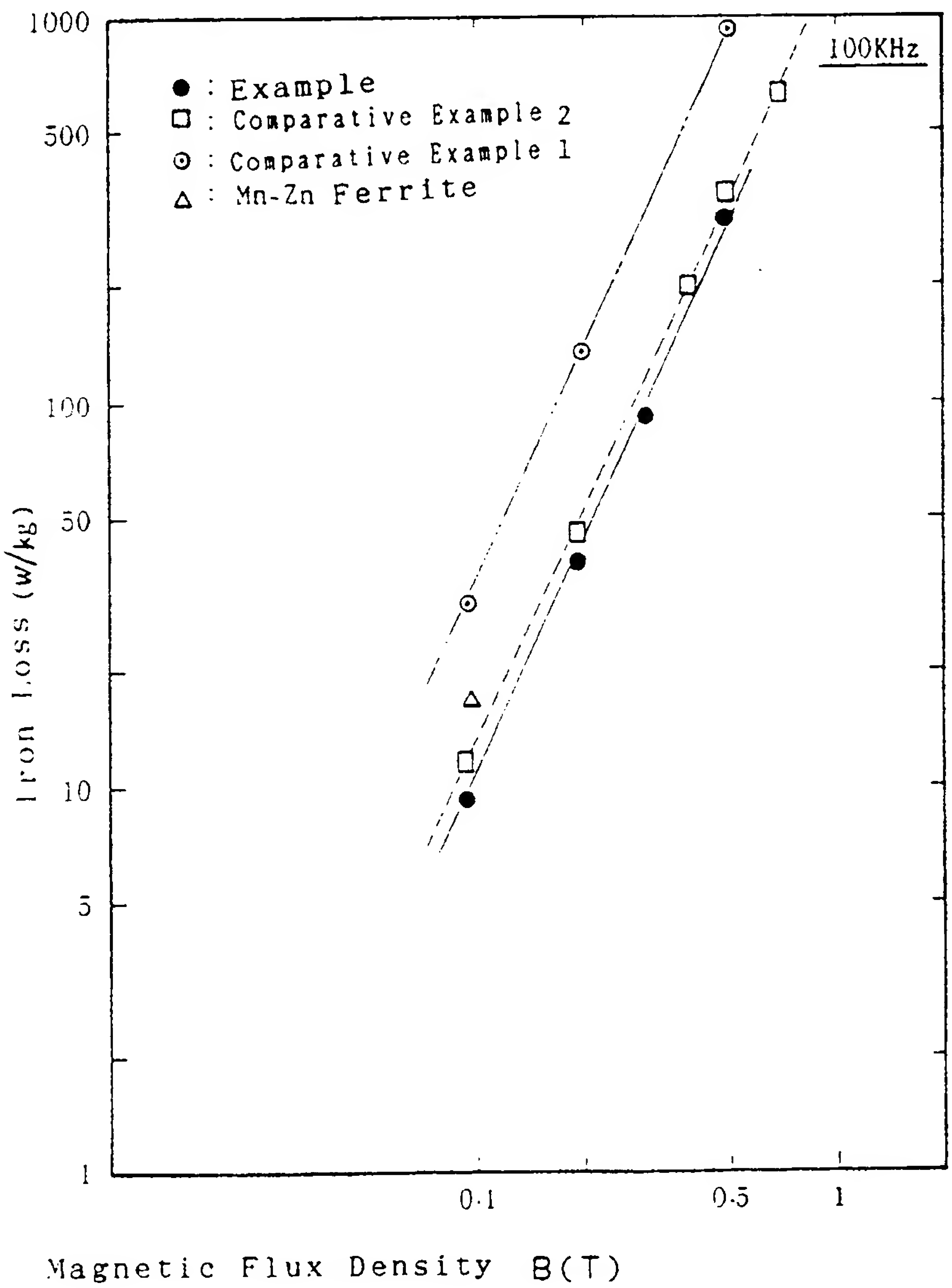

1000
500
100
50
10
5
1
Iron Loss (w/kg)
100KHz
● : Example
□ : Comparative Example 2
⊙ : Comparative Example 1
△ : Mn-Zn Ferrite
0.1
0.5
1
Magnetic Flux Density B(T)

Fig. 13

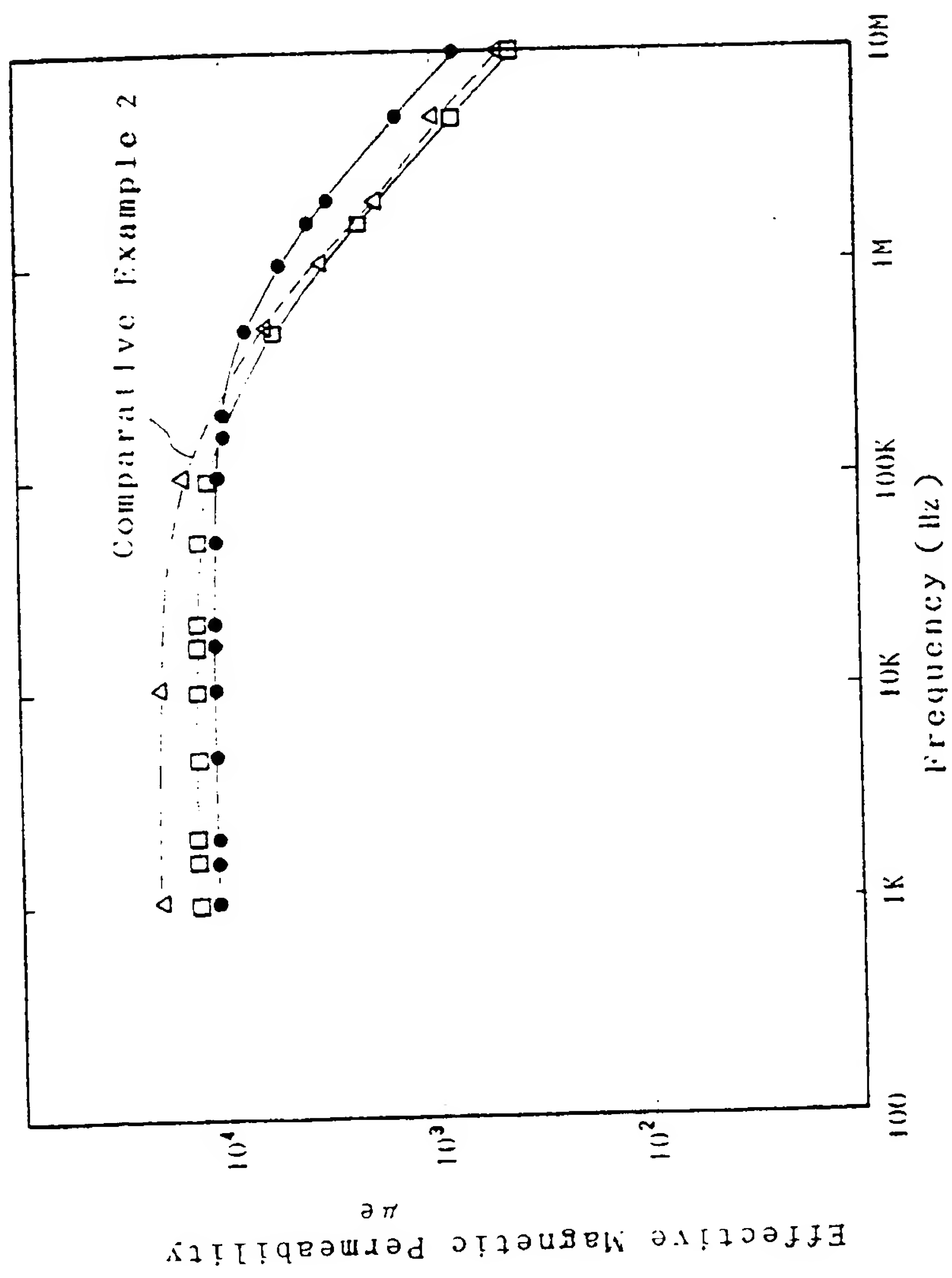

Comparative Example 2
Effective Magnetic Permeability
μe
10^4
10^3
10^2
100
1K
10K
100K
1M
10M
Frequency (Hz)

Fig. 14

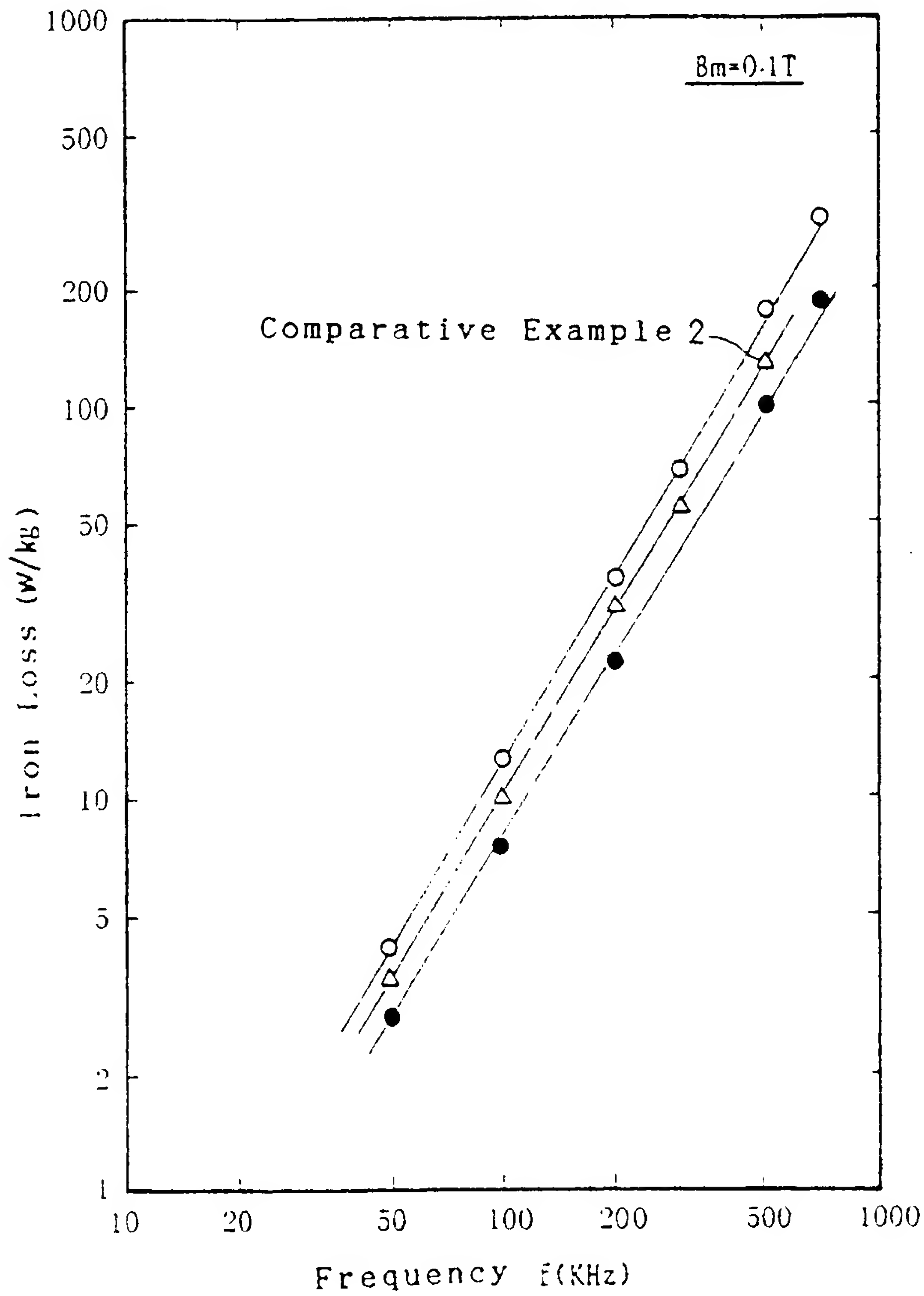

1000
500
200
100
50
20
10
5
2
1
Bm=0.1T
Comparative Example 2
Iron Loss (w/kg)
10
20
50
100
200
500
1000
Frequency f(KHz)

Fig. 15

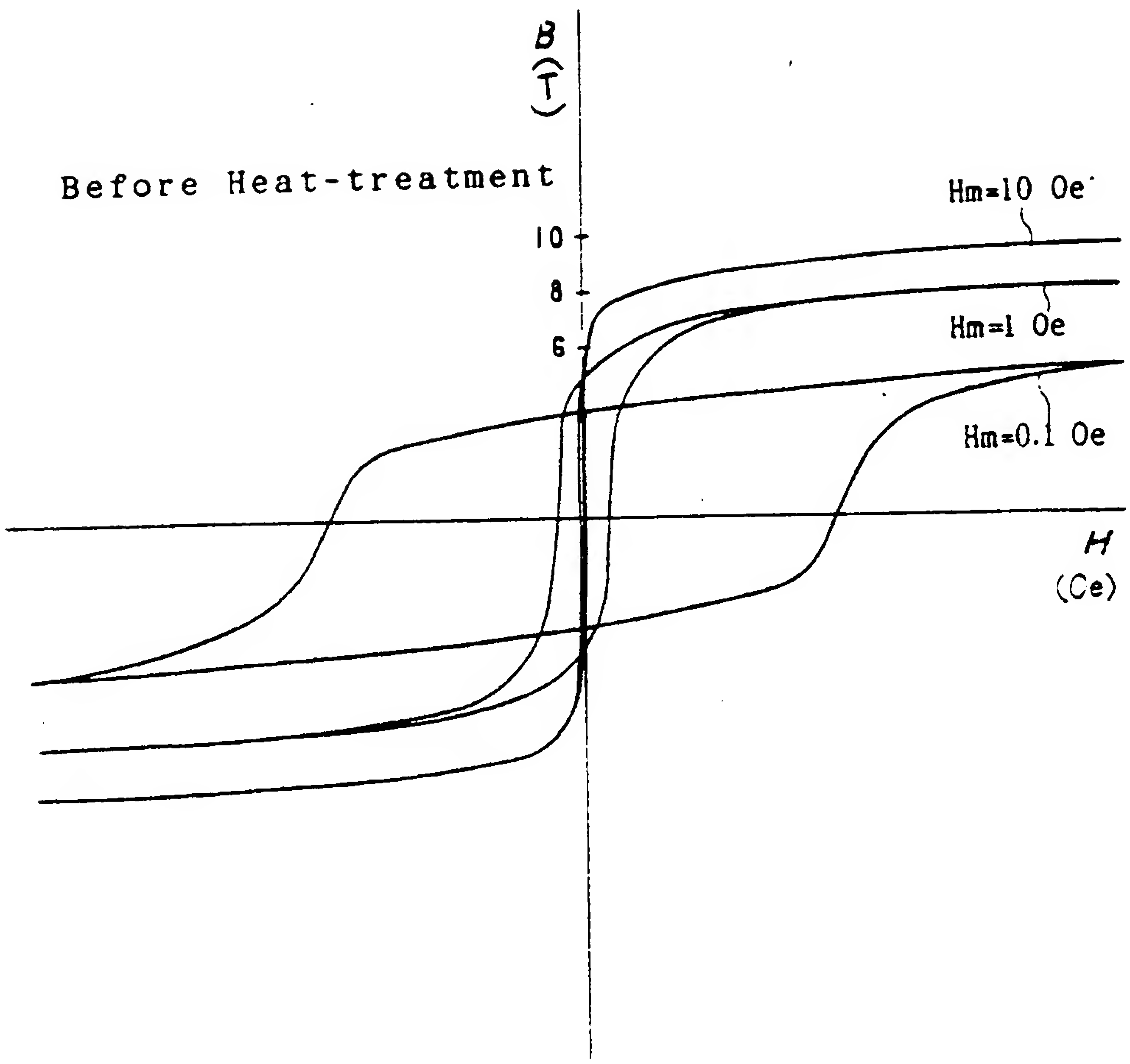


Fig. 16

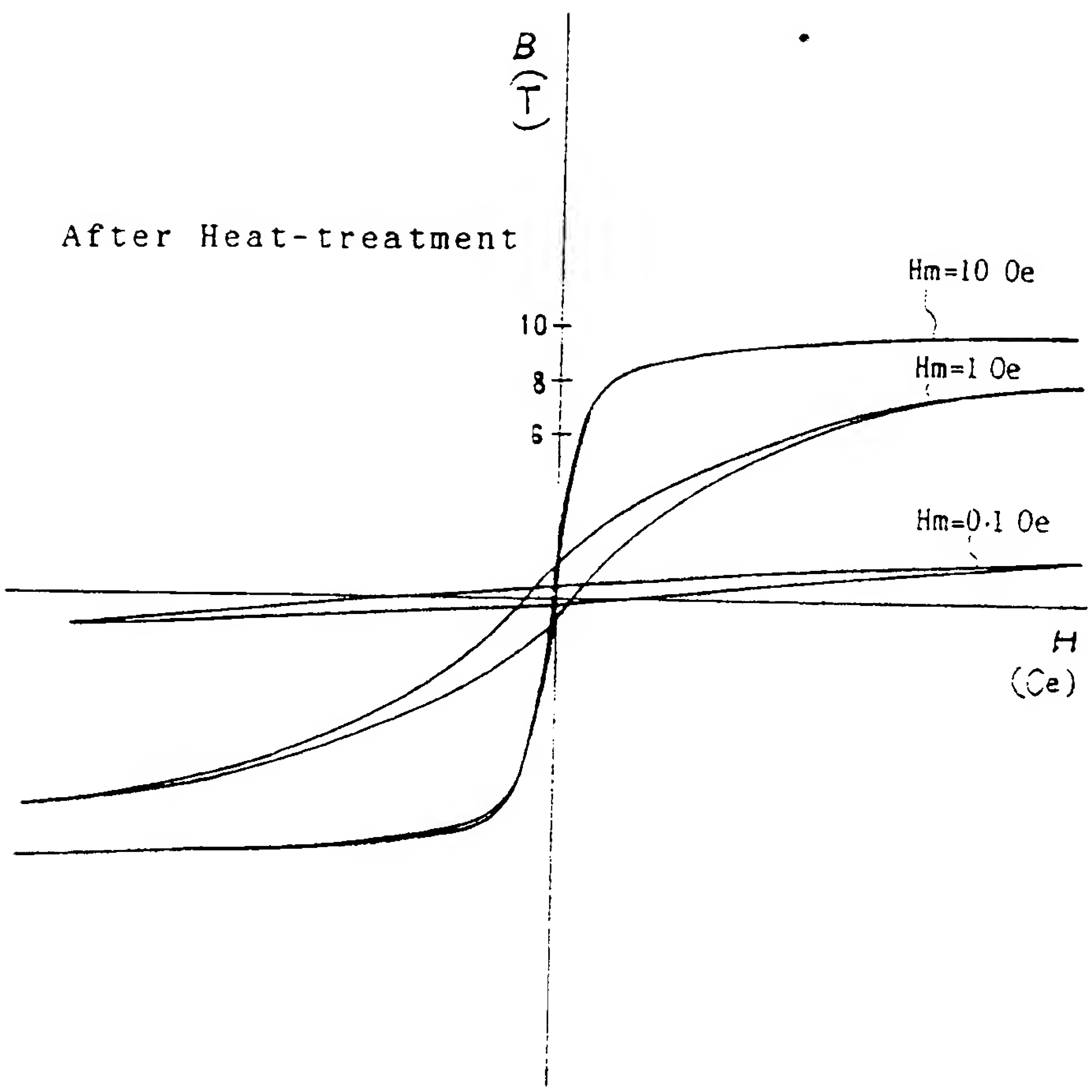
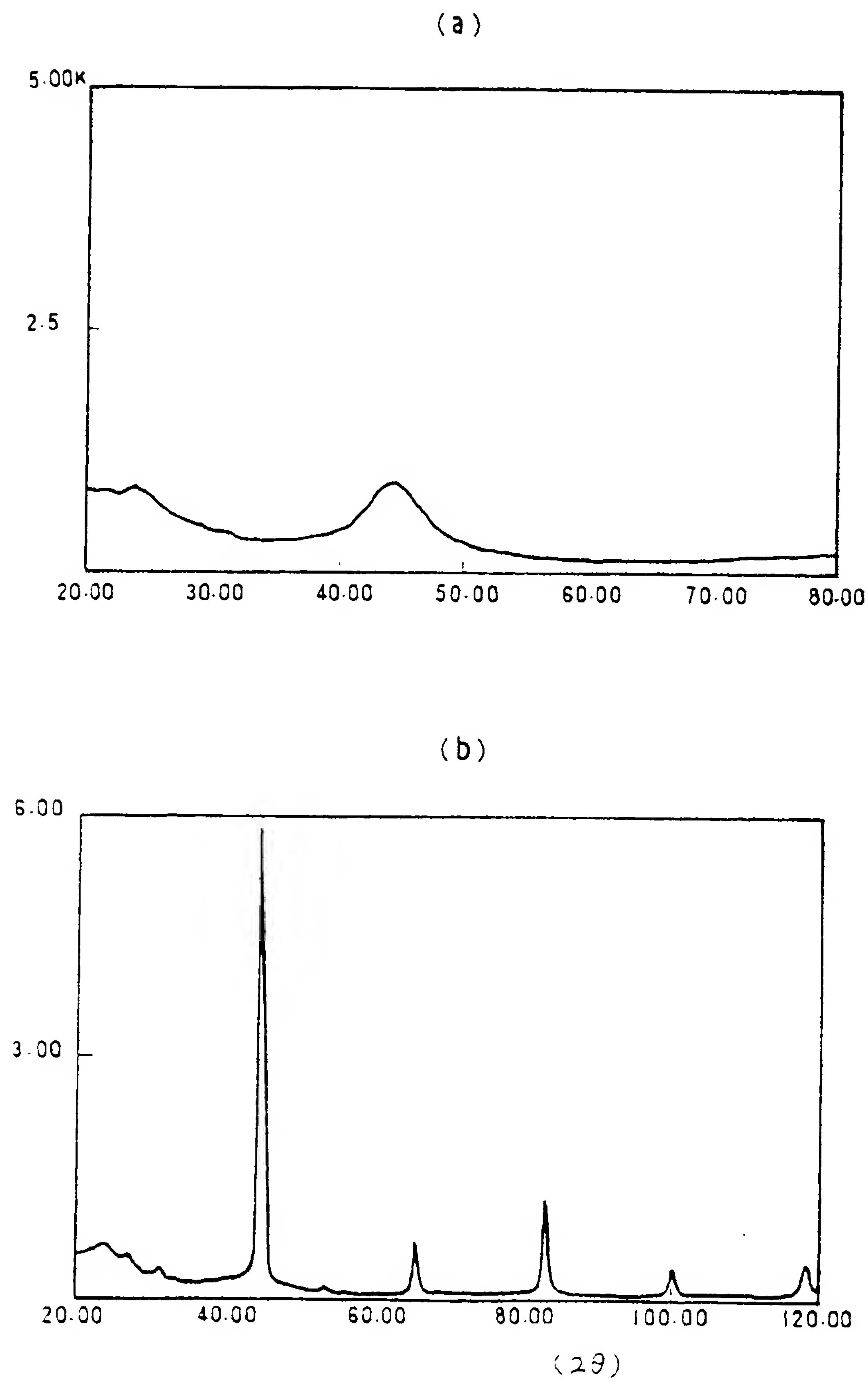


Fig. 17


(a)
5.00K
2.5
20.00
30.00
40.00
50.00
60.00
70.00
80.00
(b)
6.00
3.00
20.00
40.00
60.00
80.00
100.00
120.00
(2θ)

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/01677

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl^5 C22C45/02, 38/58

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	C22C45/02, 38/58

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	JP, A, 02-236259 (Hitachi Metals, Ltd.), September 19, 1990 (19. 09. 90), Line 5, lower left column to line 5, lower right column, page 1 (Family: none)	1-17
X	JP, A, 02-170950 (TDK Corp.), July 2, 1990 (02. 07. 90), Line 5, lower left column, page 1 to line 9, upper left column, page 2 (Family: none)	1-17
X	JP, A, 01-241200 (Hitachi Metals, Ltd.), September 26, 1989 (26. 09. 89), Line 5, lower left column, page 1 to line 20, upper right column, page 2 (Family: none)	1-17
X	JP, A, 56-158833 (Matsushita Electric Ind. Co., Ltd.), December 7, 1981 (07. 12. 81), Line 4, lower left column to line 1, lower right column, page 1 (Family: none)	1-3, 5-17

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
February 6, 1992 (06. 02. 92)	February 25, 1992 (25. 02. 92)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	